“10 LESSONS I LEARNED FROM BEING STUCK IN SPACE”

ASTRONAUT TERRY VIRTS INTERVIEW

3 FREE eBOOKS

All About Space™

APOLLO ANNIVERSARY

BACK TO THE MOON

THE FLEET OF MISSIONS THAT WILL LAND HUMANKIND ON THE LUNAR SURFACE – TO STAY

ALL-NEW AR EXPERIENCE INSIDE

FUTURE
ISSUE 118

+

SAMPLES FROM TITAN

THE VOMIT COMET

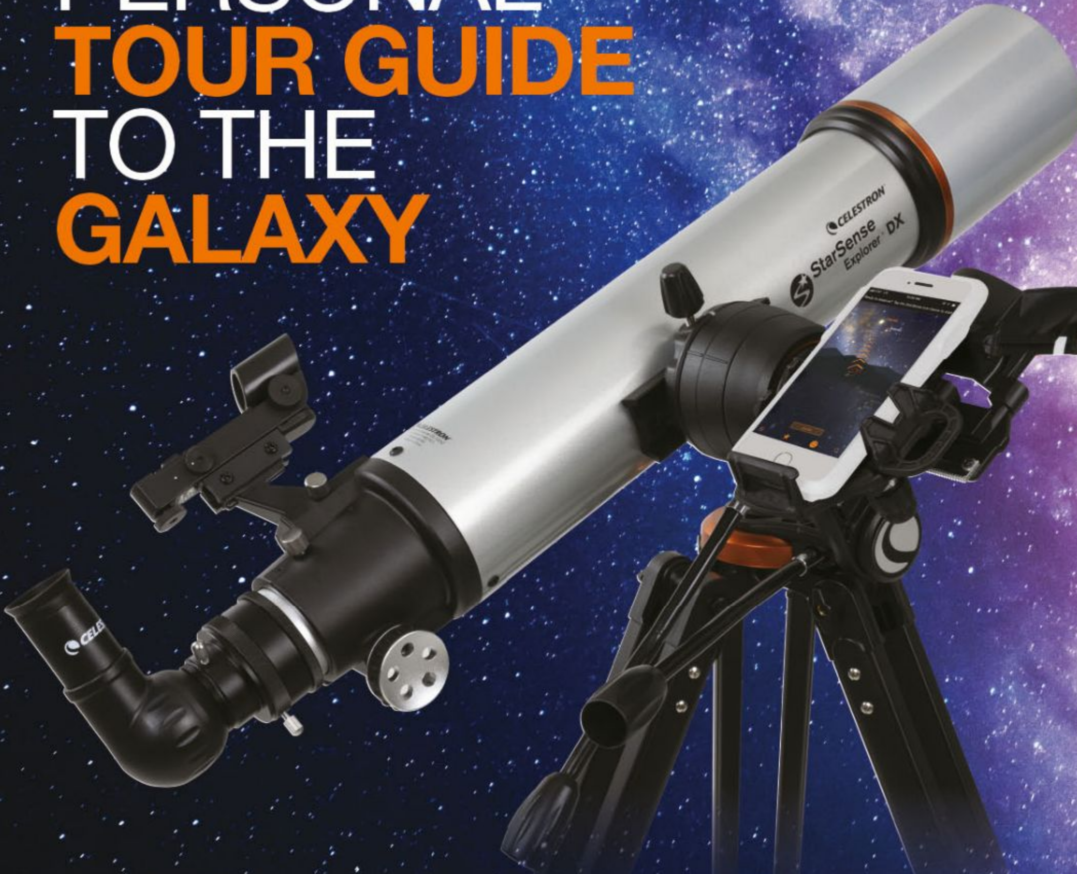
MYSTERIES FROM URANUS

Everything you need to know about

SUNLESS PLANETS

IS THERE LIFE AROUND BLACK HOLES?

NEW RESEARCH IMPACT THAT KILLED THE DINOSAURS



CELESTRON

YOUR PERSONAL **TOUR GUIDE** TO THE **GALAXY**

IMAGINE discovering stars, planets and deep sky objects in real-time whilst also being able to accurately identify what you can see.
AWARD WINNING StarSense sky technology enables you to use your smartphone with this telescope, to do just that.
VIEW incredible detail through the 102mm objective lens with our special high transmission XLT optical light coatings.
PERFECT for observing brighter objects in the City and even more from Dark Sky Sites.

StarSense Explorer™ DX

Model shown StarSense Explorer DX 102AZ RRP £379.99 (phone not included)
Other models available: StarSense Explorer DX 130AZ, DX 6" SCT, DX5" SCT, LT 70AZ, LT 80AZ, LT 114AZ and LT 127AZ

For more information visit celestron.com/ssetelescopes Contact Celestron at enquiries@celestron.com

WELCOME

Issue 118

5 ISSUE HIGHLIGHTS

Col. Terry Virts

The retired astronaut reveals the lessons he learned in Earth orbit 26

The planets with no sun

Worlds without the warmth of a host star do exist. But what are they like? 30

On board the Vomit Comet

What's it like to ride in zero-gravity? We lift the lid on the amusingly named craft 38

Life at the event horizon

Researchers are hunting for life forms around black holes – but could there be anybody out there? 42

Ask Space

Your questions answered by our team of experts 74

This month marks 52 years since humankind landed on the surface of the Moon for the very first time. A little over five decades later and we've not sent humans back since Apollo - but that's not to say the likes of NASA and the ESA, alongside a selection of private space companies, aren't once again shooting for our natural satellite.

So where are we in our plans to return to the lunar surface, stepping into the boot prints of Neil Armstrong and Buzz Aldrin? Turn to our cover feature for the plans, spacecraft and logistics that'll see us go back, this time with intention to stay.

Elsewhere in the issue, we return to the extinction of the dinosaurs: was it really an asteroid that wiped them out, or another kind of object from outer space? Reveal the worlds that wander around our galaxy without a sun, discover what it's like to board the infamous 'Vomit Comet' and uncover whether life could really exist around black holes. There's plenty to keep you entertained this month.

If you're looking for more reading material to read in the sunshine - now that the warmer weather is finally here in the Northern Hemisphere - then turn to page 95 for your free eBooks. And don't forget to check out our sister title, **How It Works**, for more science and tech!

GEMMA LAVENDER

EDITOR-IN-CHIEF

36 SUBSCRIBE TO ALL ABOUT SPACE TODAY AND YOU'LL RECEIVE

✔ Great savings off the cover price

✔ Every issue delivered straight to your door or digital device before it arrives in the shops

✔ Exclusive subscriber edition covers

KEEP IN TOUCH /AllAboutSpaceMagazine @spaceanswers space@spaceanswers.com

INSIDE

16

APOLLO ANNIVERSARY

BACK TO THE MOON

The fleet of missions that will land humankind on the lunar surface – this time to stay

95 **CLAIM YOUR FREE EBOOKS**

60 Second Science, Book of Space & Save the World

> "THIS CRITICAL STEP PUTS HUMANITY ON A PATH TO SUSTAINABLE LUNAR EXPLORATION" KATHY LUEDERS

LAUNCHPAD

06 News from around the universe
Neutron stars might be bigger than expected, while Perseverance is busy snapping away on Mars

FUTURE TECH

24 Titan sample return
A new NASA Institute of Advanced Concepts study is looking at the surprising advantages of a Titan sample return

INTERVIEW

26 Colonel Terry Virts
All About Space speaks with the former NASA astronaut about his time in space and his newfound 'cosmic perspective'

30 The Vomit Comet
You'd better have a strong stomach: in space, everyone can hear you spew

36 Worlds without suns
Astronomers are still on the hunt for rogue planets, but what can they tell us about the layout of our cosmos?

FOCUS ON

42 Cleaning a space station
Astronauts have to keep the space station clean to keep microbes under control

44 Could life exist around black holes?
They warp time and space, but could they also nurture life?

52 What killed the dinosaurs?
The object that caused Earth's last mass extinction may not have been an asteroid

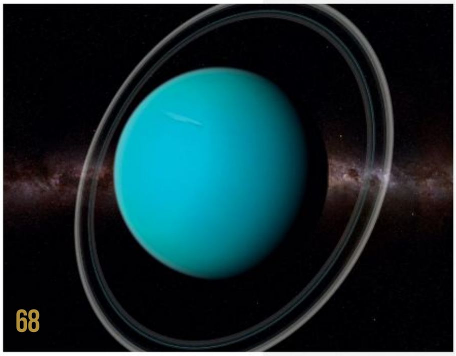
58 Remembering the Space Shuttle
Exactly a decade ago, NASA's reusable low-Earth orbital spacecraft's time came to an end. **All About Space** relives the best moments

MOON PROFILE

64 Mimas
This small, oddly shaped and icy moon continues to baffle scientists

68 Why are X-rays coming from Uranus?
When X-rays were detected from the ice giant for the first time, a team of astronomers began to look into their origin

74 Ask Space
Your questions answered by our panel of experts


68

26

44

STARGAZER

78 What's in the sky?
82 Month's planets
84 Moon tour
85 Naked eye & binocular targets
86 Deep sky challenge
88 The Northern Hemisphere
90 Astroshots
92 Telescope review
96 In the shops

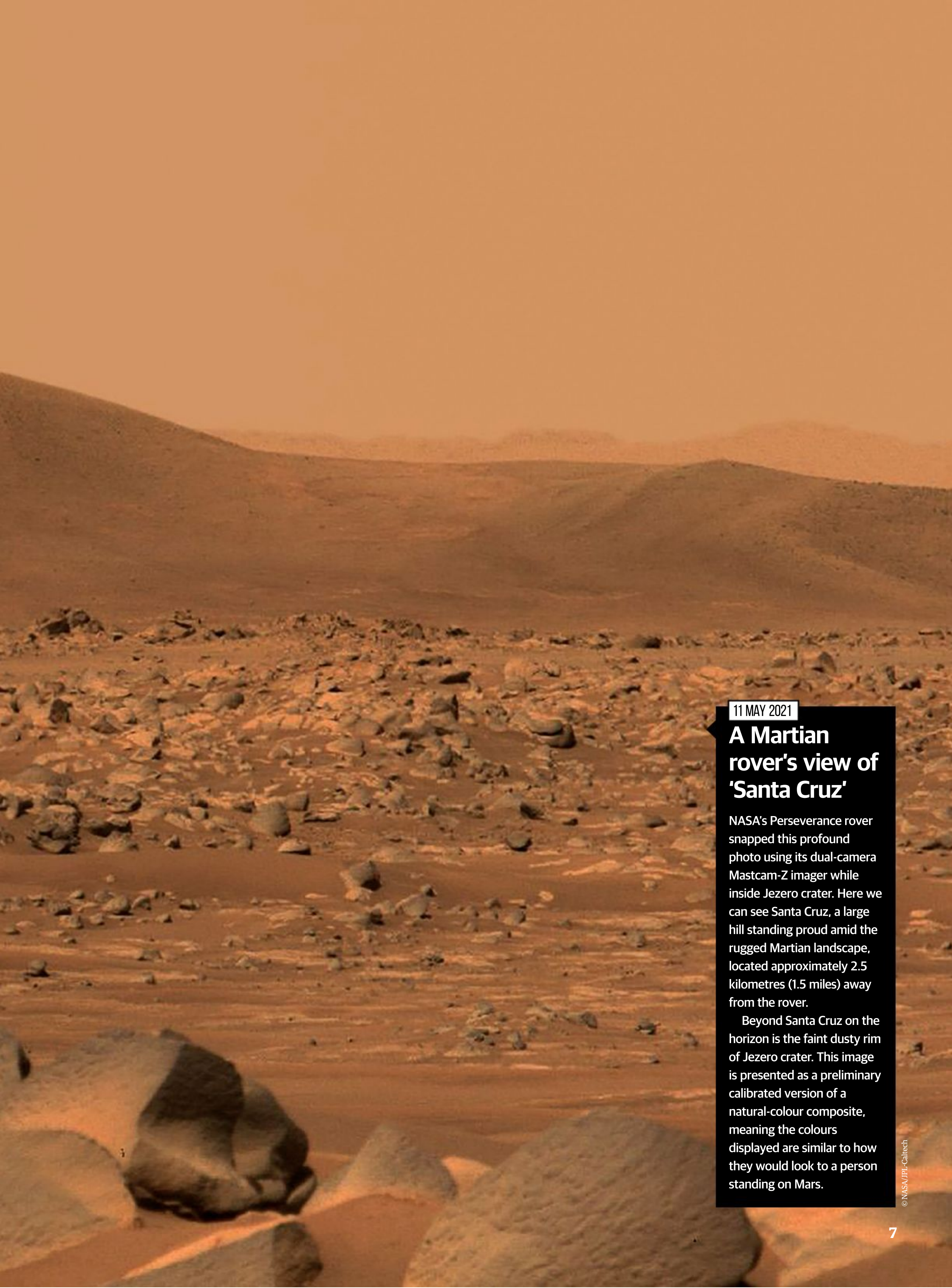
WIN!
CELESTRON NEXSTAR EVOLUTION 8
WORTH £2,000!
15

NEW AUGMENTED REALITY

Scan the QR code with your device's camera or download a free QR code reader app. Many iPhone and Android devices include these features

When you see the AR 'Scan Here' logo on the page, use your phone to scan the QR code, which looks like this

Hold your mobile device over the image and watch it come to life! Your device needs to be connected to the internet for this to function



11 MAY 2021

A Martian rover's view of 'Santa Cruz'

NASA's Perseverance rover snapped this profound photo using its dual-camera Mastcam-Z imager while inside Jezero crater. Here we can see Santa Cruz, a large hill standing proud amid the rugged Martian landscape, located approximately 2.5 kilometres (1.5 miles) away from the rover.

Beyond Santa Cruz on the horizon is the faint dusty rim of Jezero crater. This image is presented as a preliminary calibrated version of a natural-colour composite, meaning the colours displayed are similar to how they would look to a person standing on Mars.

© NASA/JPL-Caltech

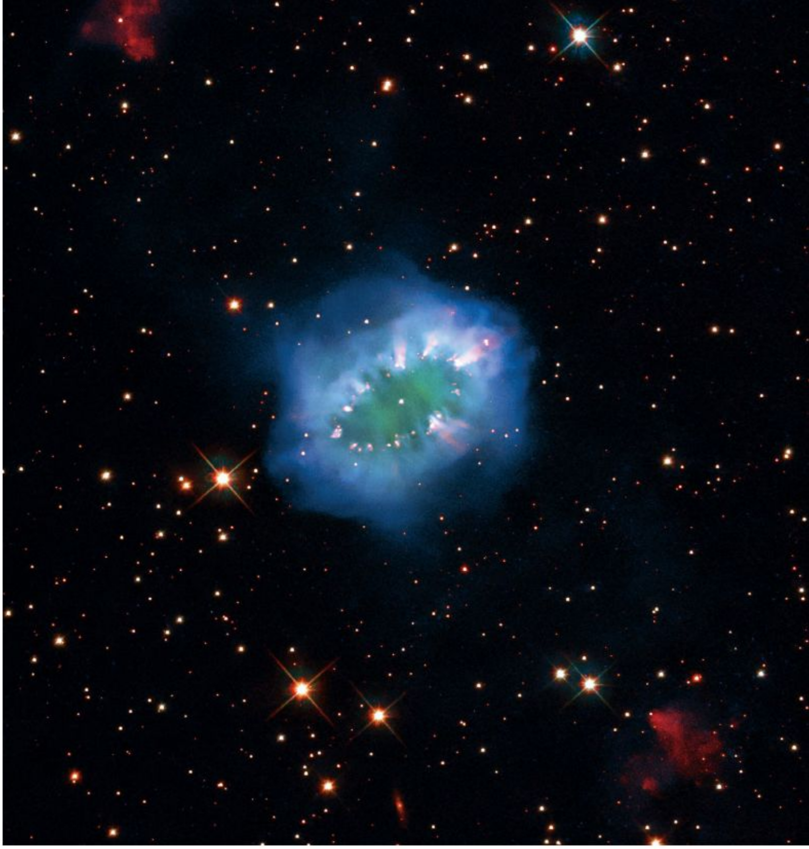
26 APRIL 2021

Star-studded necklace

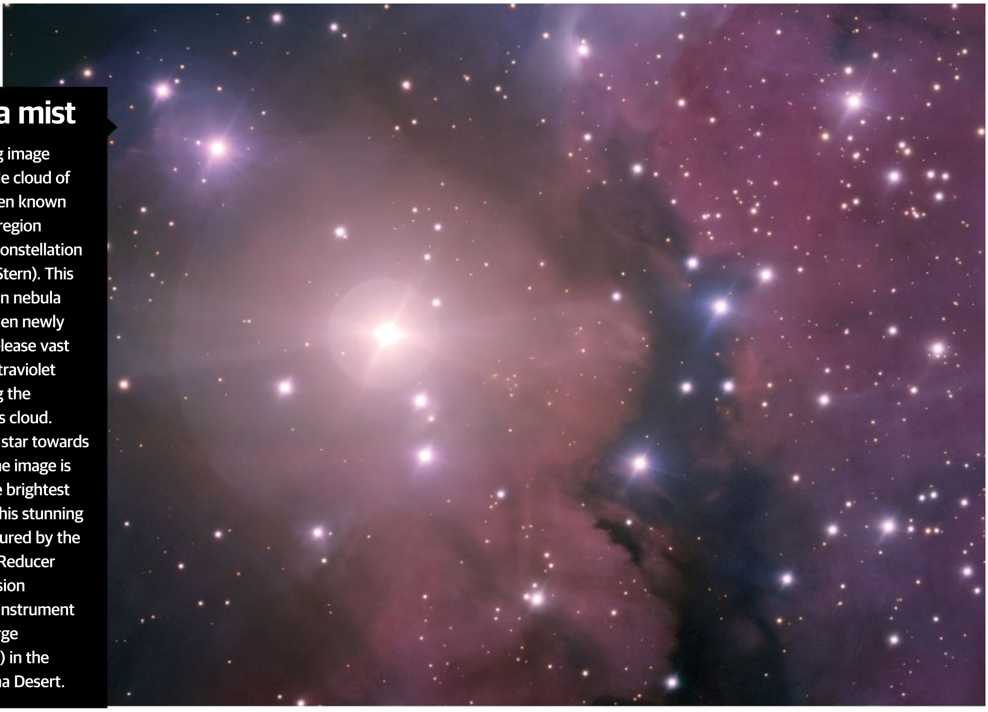
The exquisite and aptly named Necklace Nebula, officially PN G054.2-03.4, is located 15,000 light years away in the constellation of Sagitta (the Arrow). This celestial jewel was forged approximately 10,000 years ago by two doomed Sun-like stars locked in a very tight orbit.

One of the ageing stars proceeded to consume its smaller companion, creating what astronomers call a 'common envelope' – gas that contains a binary star system.

This process caused the expulsion of vast quantities of gas and dust, which now forms the ring that gives the Necklace Nebula its famous shape.



© ESA/Hubble & NASA



© ESO

10 MAY 2021

Magenta mist

This captivating image exhibits a purple cloud of ionised hydrogen known as DG121, a HII region located in the constellation of Puppis (the Stern). This type of emission nebula is produced when newly formed stars release vast quantities of ultraviolet energy, ionising the surrounding gas cloud.

The dazzling star towards the centre of the image is HD 60068, the brightest in the region. This stunning scene was captured by the FORS 2 (FOcal Reducer and low dispersion Spectrograph) instrument on the Very Large Telescope (VLT) in the Chilean Atacama Desert.

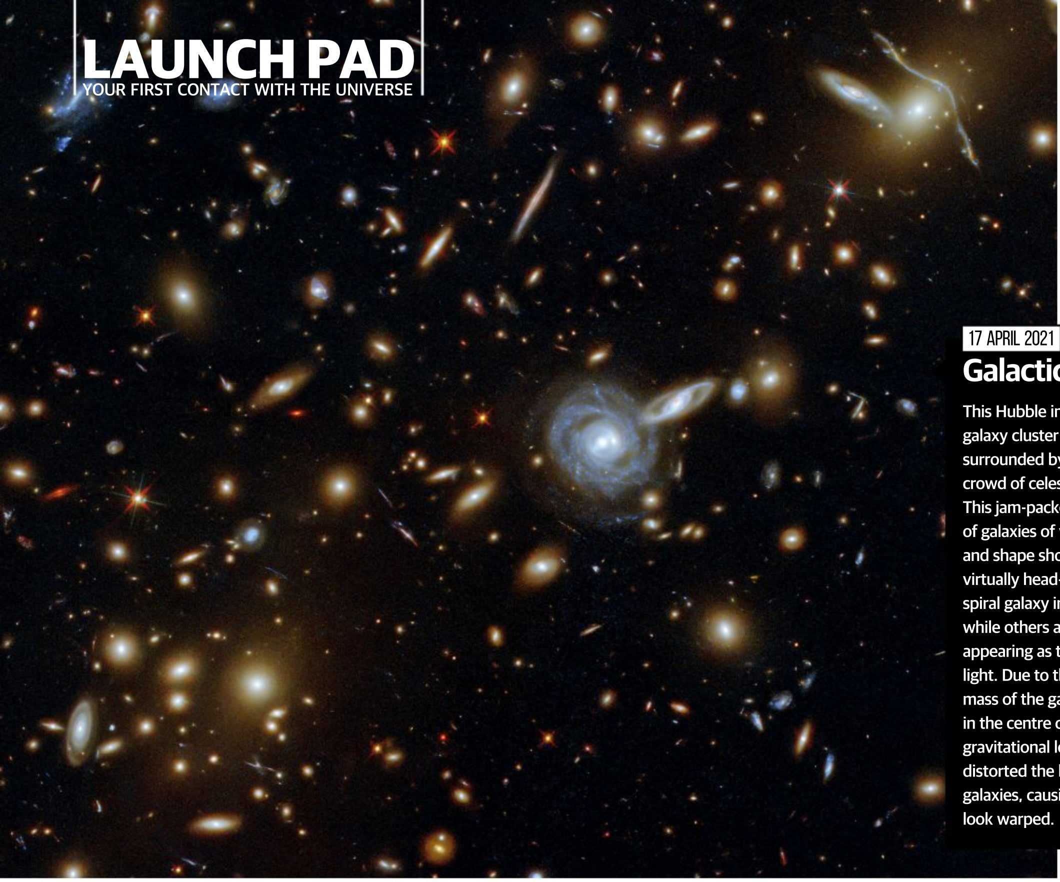
© NASA

2 MAY 2021

Rare nocturnal splashdown

This impressive drone image shows the recovery of the SpaceX Crew Dragon Resilience's passengers after they splashed down in the Gulf of Mexico off the coast of Panama City, Florida, in the early hours of the morning on 2 May 2021.

This was the first nighttime splashdown with American astronauts since the Apollo era, signifying the completion of SpaceX's first full-fledged crewed mission to the ISS. Working under cover of darkness, recovery crews successfully retrieved NASA astronauts Mike Hopkins, Victor Glover and Shannon Walker and JAXA astronaut Soichi Noguchi.



17 APRIL 2021

Galactic soup

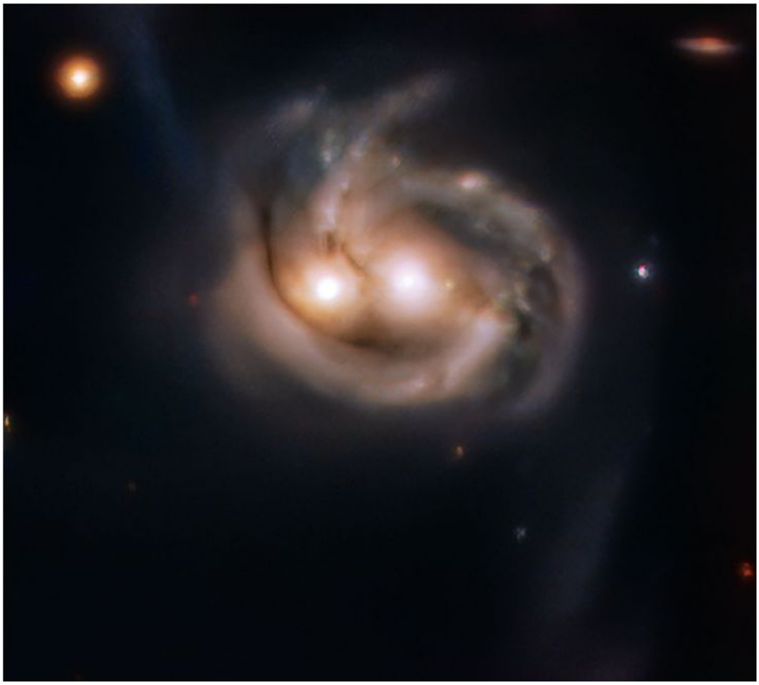
This Hubble image presents galaxy cluster ACO S 295 surrounded by a bustling crowd of celestial objects. This jam-packed menagerie of galaxies of varying size and shape shows some virtually head-on, like the spiral galaxy in the centre, while others are edge-on, appearing as thin slithers of light. Due to the significant mass of the galaxy cluster in the centre of the image, gravitational lensing has distorted the background galaxies, causing them to look warped.

© ESA/Hubble & NASA

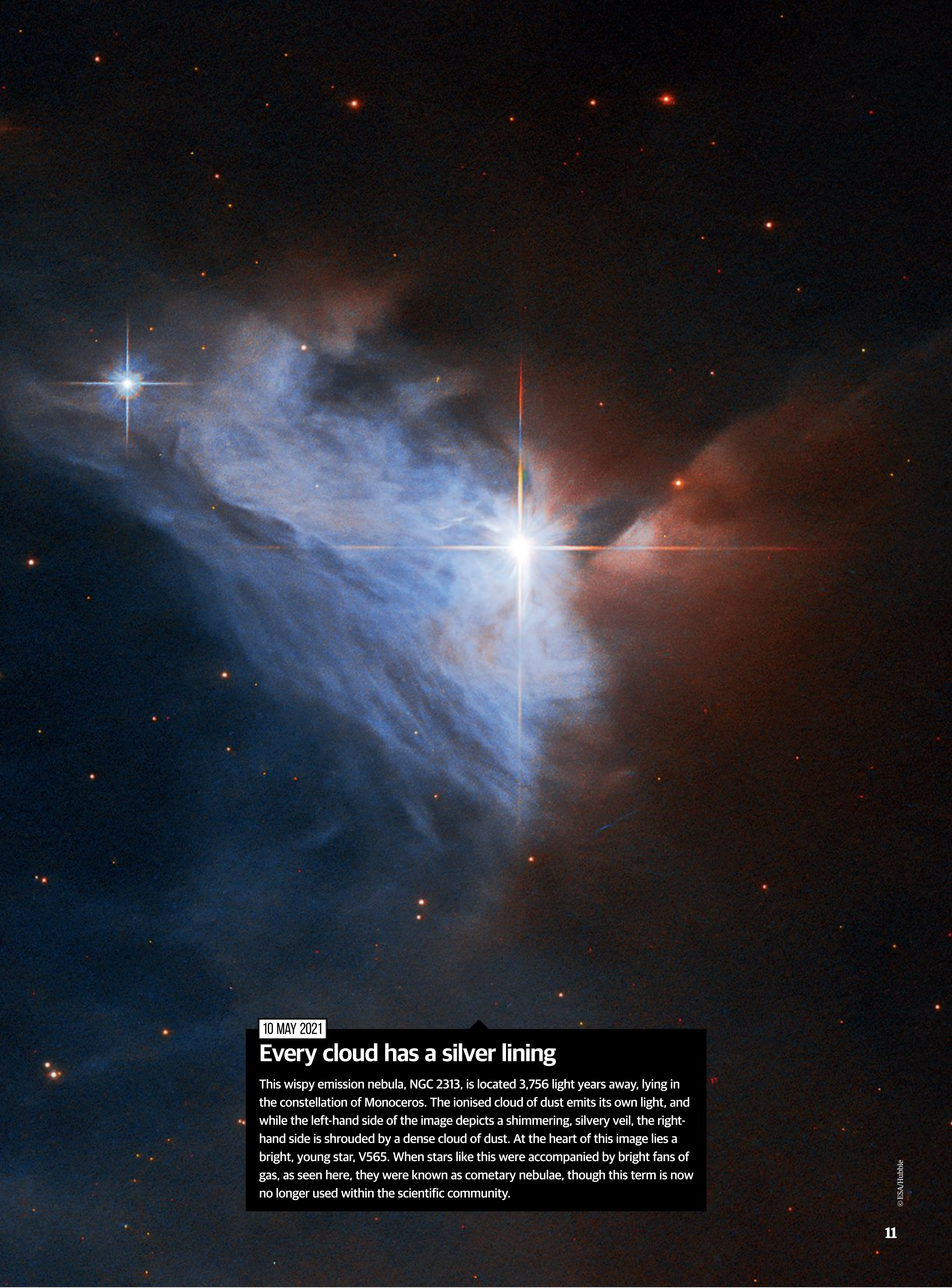
25 FEBRUARY 2021

Say cheese!

This friendly face is the product of two colliding galaxies, and doesn't Mrk 739 look rather pleased with itself? It should be, as such mergers are rare in our galactic neighbourhood, and Mrk 739 is helping scientists better understand these colossal events. Due to its relatively close proximity at 425 million light years away, scientists are able to keep a watchful eye on Mrk 739 using instruments such as the Multi Unit Spectroscopic Explorer (MUSE) on the VLT. This provides information on the motions of galaxies, the age of their stars and what they're made of.



© ESO



10 MAY 2021

Every cloud has a silver lining

This wispy emission nebula, NGC 2313, is located 3,756 light years away, lying in the constellation of Monoceros. The ionised cloud of dust emits its own light, and while the left-hand side of the image depicts a shimmering, silvery veil, the right-hand side is shrouded by a dense cloud of dust. At the heart of this image lies a bright, young star, V565. When stars like this were accompanied by bright fans of gas, as seen here, they were known as cometary nebulae, though this term is now no longer used within the scientific community.

© ESA/Hubble

Neutron stars may be bigger than expected thanks to an outer shell

CITY-SIZE NEUTRON STARS MAY ACTUALLY BE BIGGER THAN WE THOUGHT

Words by Tereza Pultarova

Scientists have found neutron stars - the densest known objects in the universe aside from black holes - have a radius of between 13.25 and 14.25 kilometres (8.2 and 8.9 miles). Previously it was believed these stars, leftovers of huge supernova explosions, have a slightly smaller radius of up to 12 kilometres (7.5 miles). Within this relatively small radius - whichever one you look at - an amount of matter that equals 1.4 times the mass of the Sun is squeezed. The Sun, in comparison, has a radius of 695,508 kilometres (432,169 miles).

These estimates were made not by measuring neutron stars directly, but by looking at the so-called 'neutron skin', or an outer layer of neutrons, surrounding the nucleus of a lead atom. But what does lead have to do with the size of neutron stars? Lead is one of the densest materials that can be naturally found on Earth. Even though lead is nowhere near as dense as neutron stars, scientists assume that the physical principles governing the structure of lead atoms must be similar to those behind the structure of neutron stars.

"There is no experiment that we can carry out in the laboratory that can probe the structure of the neutron star," said Jorge Piekarewicz, a nuclear physicist at Florida State University. "A neutron star is such an exotic object that we have not been able to recreate it in the lab, so anything that can be done in the lab to constrain or inform us about the properties of a neutron star is very helpful." The researchers probed lead atoms with electron beams and found that the neutron skin of the lead isotope Pb-208 is 0.28 femtometres (0.28 trillionths of a millimetre) thick, about double the thickness predicted.

Atoms generally contain positively charged protons, negatively charged electrons and neutrons with no charge. Protons are squeezed inside the atom's nucleus, while electrons make up its outer shell. With neutrons, it's a bit more complex. Heavier atoms, such as lead, usually have more neutrons. Some of these neutrons are squeezed in the nucleus together with the protons, but not all of them fit. The rest are pushed out to the edge of the nucleus, forming what physicists call the neutron skin.

The most common isotope of lead, Pb-208, which is frequently used for experiments, contains 82 protons and 126 neutrons. Physicists know that the size of the skin correlates with the size of the atom. Piekarewicz believes the same can be assumed about the much bigger and denser neutron stars. "The dimensions of that skin, how it extends further, is something that correlates with the size of the neutron star," said Piekarewicz, though he added that his estimates were rather preliminary. More work and advancements in technology would be needed for scientists to really get a proper grasp of neutron stars.

> "THERE IS NO EXPERIMENT THAT CAN PROBE THE STRUCTURE OF THE NEUTRON STAR"

© NASA

© NASA

SCIENTISTS PONDER HOW TO GET SAMPLES FROM SATURN'S WEIRD MOON TITAN

Words by Tereza Pultarova

A sample-return mission to Saturn's moon Titan could discover unexpected forms of life and bring back chemical compounds that cannot be found on Earth. A team of engineers from the NASA Glenn Research Center in Cleveland, Ohio, has recently received a $125,000 (£88,000) NASA Innovative Advanced Concepts (NIAC) grant to look into the feasibility of bringing a sample of material from this intriguing world to Earth.

"We expect landing on Titan to be relatively easy," said Steven Oleson, head of the Compass Lab at Glenn. "Titan has a thick atmosphere of nitrogen – 1.5 times the atmospheric pressure of Earth – which can slow the lander's velocity with an aeroshell and a parachute for a soft landing, just like astronauts returning to Earth. With the landing out of the way, the next big challenge would be to get the sample up to space, on its way back to Earth. For that, the Glenn team envisions, the surface lakes of methane will come in handy.

"Producing rocket fuel on Titan wouldn't require chemical processing – you just need a pipe and a pump," said Oleson. "The methane is already in a liquid state, so it's ready to go." The Compass Lab team will now investigate how to effectively produce liquid oxygen to enable the fuel to burn. Although the sample-return concept may never fly, Titan can expect a robotic visitor soon. Dragonfly is an eight-bladed rotorcraft scheduled to begin the eight-year journey to the Saturn system in 2027.

Above: Titan's conditions are favourable for landing a craft

Below: Astronauts wear this one piece under their spacesuits when they go out on spacewalks

ASTRONAUTS MAY FINALLY START CLEANING THEIR SPACE UNDERWEAR, USING MICROBES

Words by Mindy Weisberger

We can all agree that sharing your unwashed underwear with another person isn't ideal. But for astronauts on the International Space Station (ISS), performing a spacewalk requires that they share not only the spacesuits, but also a next-to-the-skin piece of clothing that's worn underneath, known as the Liquid Cooling and Ventilation Garment (LCVG). Access to a freshly laundered LCVG isn't an option on the ISS, but technicians with the European Space Agency (ESA) are taking steps to improve the antimicrobial properties in LCVG materials to keep these shared garments clean and fresh for longer.

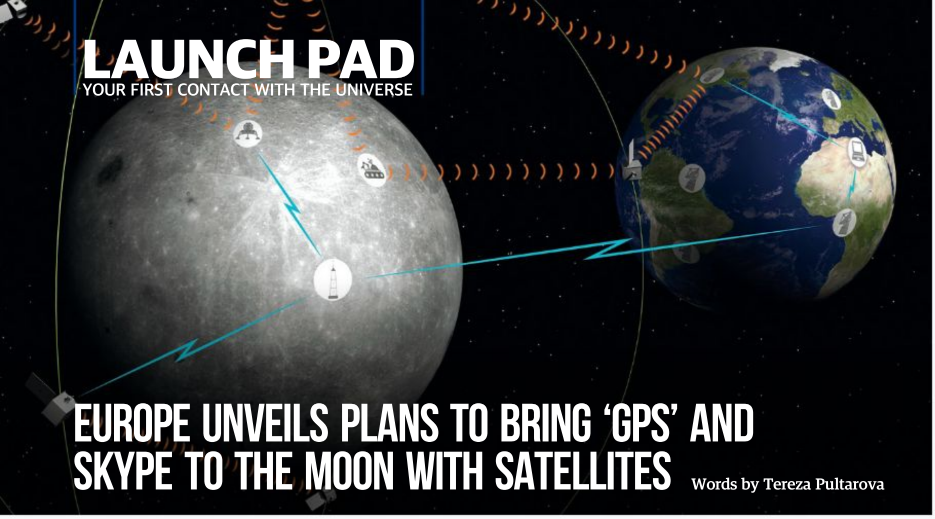
In a new project called Biocidal Advanced Coating Technology for Reducing Microbial Activity, ESA researchers are collaborating with the Vienna Textile Lab, a biotechnology company that produces fabric dyes from bacteria. Compounds generated by these bacteria can make textile fibres more resistant to certain types of microbes.

Astronauts on the ISS keep their hands and bodies clean with no-rinse cleaning solutions and dry shampoo, but laundering clothes – including underwear – would require too much water and is simply not possible. Nor is there enough room on the ISS for astronauts to pack a fresh change of clothes for every day of their mission.

Scientists were already investigating materials for upgrading outer spacesuit layers, so this "is a useful complement, looking into small bacteria-killing molecules that may be useful for all kinds of spaceflight textiles," said ESA material engineer Malgorzata Holynska.

© NASA

HOW IT WORKS
subscription offer
FROM £2.20 PER ISSUE!
PRINT
£3.28 PER ISSUE!
DIGITAL
£2.20 PER ISSUE!
PRINT & DIGITAL
£3.67 PER ISSUE!
This offer is **only** available via our online shop
www.magazinesdirect.com



© ESA

EUROPE UNVEILS PLANS TO BRING 'GPS' AND SKYPE TO THE MOON WITH SATELLITES

Words by Tereza Pultarova

The ESA has kicked off development of a satellite constellation that will orbit the Moon and provide navigation and telecommunication services to lunar explorers. If all goes according to plan, the new system could be in place in the late 2020s. The ESA believes that Earth's celestial companion is set to become a busy destination, with commercial companies and nations from across the world all wanting a slice of the 'eighth continent'.

The new constellation, called Moonlight, will make it easier and cheaper for a fledgling lunar economy to blossom. For now contracts have been awarded to two European industrial consortia to study the feasibility of such an undertaking over the next year and a half and propose technical solutions for the ESA to choose from.

A mission called the Lunar Pathfinder is already in the works, which will test the novel GNSS receiver in orbit around the Moon. The satellite, built by the UK-based Surrey Satellite Technology (SSTL), is scheduled to launch in 2024. SSTL also leads one of the consortia that will develop the proposal for the new constellation. The other is headed by Italy's Telespazio.

The constellation will likely consist of three or four satellites. Additional satellites might be added to beef up the communications aspect of the offering. The ESA expects the constellation will be operated by the private sector, which will sell the service to the agency and other customers in a similar fashion to how SpaceX sells service missions and crew launches to the ISS.

Above: The satellites will improve lunar navigation

METALS FOUND IN THE ATMOSPHERES OF COMETS SURPRISE SCIENTISTS

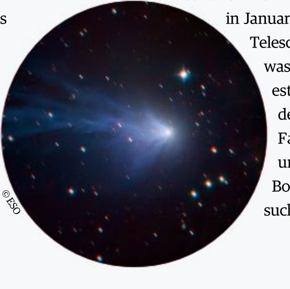
Words by Charles Q. Choi

Metal atoms have surprisingly been discovered in the frigid atmosphere of the first known interstellar comet to visit our Solar System. Astronomers have also detected metal in the cold halos surrounding comets local to the Solar System, which suggest our Solar System comets and the interstellar visitor may have similar origins.

Scientists often deduce the composition of comets by examining the clouds of gas and dust known as comas that surround the hearts of comets. Scientists do not typically detect metals such as nickel in the comas of comets, since their surfaces are usually too cold for metal to vaporise.

Exceptions to this rule are comets passing near or plunging into the Sun, where temperatures can readily exceed the 425 degrees Celsius (800 degrees Fahrenheit) needed for nickel vapour to form. Now scientists have detected nickel atoms in the coma of the first known interstellar comet, 2I/Borisov. First discovered in 2019, its speed and trajectory revealed it was a rogue comet from interstellar space, making it the first known interstellar comet and the second known interstellar visitor after the cigar-shaped rock 1I/2017 U1, or 'Oumuamua.

The discovery was unexpected – when astronomers first saw these nickel atoms in January using the Very Large Telescope in Chile, 2I/Borisov was far from the Sun, with an estimated temperature of -93 degrees Celsius (-135 degrees Fahrenheit). It remains uncertain how comets like 2I/Borisov can generate metal at such cold temperatures.



© ESO

Left: Nickel vapour has been identified in cometary coma

Right: Blue Ghost will be Firefly's first launch

IN COOPERATION WITH SPACE.com

FIREFLY AEROSPACE PICKS SPACEX ROCKET TO LAUNCH BLUE GHOST MOON LANDER IN 2023

Words by Rahul Rao

Space launch company Firefly Aerospace announced that when its Blue Ghost lander launches to the Moon in 2023, it will do so on a SpaceX Falcon 9. The Falcon 9 will be able to carry Blue Ghost to the Moon without forcing the lander to expend much of the fuel it might need for the actual touchdown, said Shea Ferring, Firefly's senior vice president of spacecraft.

Firefly has yet to launch anything, though in June the Texas company hopes to begin testing its own rocket for small launches: Firefly Alpha. Nonetheless, the company has been active in designing lunar landers, and it's paid off. In February NASA awarded Firefly a contract to deliver Blue Ghost to the Moon.

Blue Ghost is part of NASA's Commercial Lunar Payload Services (CLPS) program, which contracts private-sector firms to land science experiments and other assorted cargo on the Moon. The first CLPS missions could launch as soon as this year.

© Firefly

WIN

CELESTRON NEXSTAR EVOLUTION 8

Take a high-definition tour of the universe at the touch of a button

Powerful, portable and versatile: these are just some of the words used to describe the Celestron NexStar Evolution 8, which offers superb views of everything from the Moon and planets to deep-sky objects such as galaxies and nebulae.

With the help of StarBright XLT multi-coating, light transmission is increased, and combined with anti-reflection multi-coated lenses, reflective multi-coated mirrors and four-element rare-earth glass, superb views with high definition and clarity are guaranteed from one observing session to the next.

The beauty of the Evolution 8 is the ease in which you can use and control it. You can either download Celestron's free SkyPortal navigation app for Android and iOS, which will expand the capabilities of your instrument thanks to a database of over 120,000 objects, or make use of the Evolution 8's controller, which can assist in properly aligning the tube, allowing for some stunning tours of objects and astronomical events.

What's more, the Evolution 8 is effortlessly portable, featuring a long-life lithium-iron phosphate battery which can provide up to ten hours of continual use, leaving you unhindered in your adventures around the night sky.

CELESTRON

To be in with a chance of winning, answer this question:

Which of these planets doesn't have rings?

A: Saturn **B:** Mars **C:** Uranus

Competition ends on 14 July 2021

Enter online at **surveymonkey.co.uk/r/AAS118COMP**

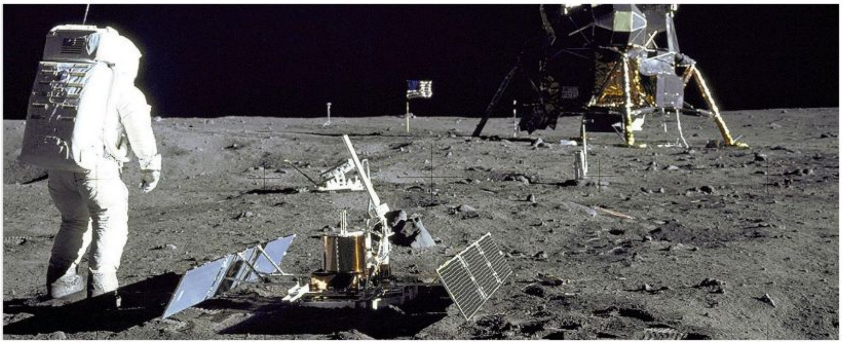
Visit the website for full terms and conditions at **futureplc.com/terms-conditions**

APOLLO ANNIVERSARY

BACK TO THE MOON

MANY NATIONS ARE INTERESTED IN RETURNING TO THE MOON TO EXPLORE AND MINE IT

Reported by Ian Parker



© NASA

Above: 12 people have walked on the Moon, and all of them were American. That should change in the next decade

Since the first humans evolved in east Africa about 3 million years ago, people have been conflicted between the pressures of dealing with problems at home and the excitement and possibilities offered by exploration. There will always be problems at home, but it's not a good enough reason for staying put, so people venture forth, often reaping the benefits.

There is much historical evidence to show that exploration produces solutions which can be employed back home. Columbus struggled to fund his expeditions because few could see any benefit. But after Europeans reached the Americas they brought back potatoes, which became a hugely important crop, feeding millions because they thrive where other crops fail.

Discoveries are made not only at the destination, but along the way, too. When sailors began to explore the world's oceans, they needed a way of determining longitude, something which requires accurate timings. Since pendulum clocks are wildly inaccurate on rolling ships, major scientific and engineering advances were made in coming up with a timepiece solution. Your wristwatch, albeit probably electronic, is a direct descendant of that.

We discuss all of this for a reason. Since moonwalkers Gene Cernan and Harrison Schmitt splashed down on Earth along with Command Module pilot Ronald Evans (and five mice) on 19 December 1972, humans have never again put boots on the Moon. Several return programs have been proposed and aborted, with none being successful because of funding problems and a lack of enthusiasm from the public and politicians. Earthbound problems have been seen as more pressing.

But times are changing. Despite the ravages of COVID-19 on health and budgets, space agencies are getting serious about returning astronauts to Earth's only natural satellite. And one fact that the pandemic has reinforced is that there is not a fixed amount of money on Earth: governments can create it in an economic process called quantitative easing. President Joe Biden is planning a trillion-dollar stimulus package for the US economy, and it's paving the way for exploration.

This time around, NASA astronauts heading for the Moon are likely to include a woman and a person of colour for the first time, reversing the discriminatory wrongdoings of the past, which is an important part of many government policies. But a return to the Moon is nevertheless being seen as a stepping stone for other, perhaps more ambitious missions. Buzz Aldrin, the second human to walk on the Moon's surface, supports a manned mission to Mars, and NASA is not alone in looking skywards.

As it stands, there's an internal fight going on within the wider space industry, and an argument about whether we should be sending people at all. Having humans in space, or on another celestial body such as the Moon, is much more expensive than sending unmanned craft. Consider the great success that the Mars 2020 mission's helicopter Ingenuity has recently enjoyed. There's a strong argument that money is far better spent on unmanned spacecraft and landers.

Even so, NASA is getting ready to send astronauts to explore more of the Moon as part of the Artemis program, and the agency has selected SpaceX to continue development of the first commercial human lander that will carry the next two American astronauts to the lunar surface. In Greek mythology, Artemis was the daughter

© NASA

THE MISSIONS TO LAND ON THE MOON

NASA's Artemis and China and Russia's ILRS program are attracting the support of many other nations

NASA'S ARTEMIS

☑ Stepping stone to Mars
☑ First woman on the Moon
☑ First person of colour on the Moon
☑ Collaboration with commercial partners
☑ Aims to build sustainable elements on the surface

Artemis currently has three missions planned, starting with the test of an unmanned Orion spacecraft. The second will be manned and fly around the Moon. The third will touch down.

CHINA AND RUSSIA'S INTERNATIONAL LUNAR RESEARCH STATION

☑ A proposed joint-venture research facility
☑ Open to all interested countries and international partners
☑ Either built on the lunar south pole or in orbit
☑ Human presence will follow a robotic stage
☑ The ESA is interested, although it's signed an agreement with NASA

Human exploitation of the Moon may well involve mining, so samples will be important. The Chinese and Russian ILRS – which will focus on water and mineral resources – could lead the way to this.

TAP HERE TO PLAY

RETURNING TO THE MOON

The US, China and Russia plan to put boots back on the Moon before the end of the decade with the support of international partners

2021

German aerospace company PTScientists is looking to launch the world's first-ever private Moon landing. It will use the Autonomous Landing and Navigation Module, which will deploy two rovers.

1 OCTOBER 2021

The Russian space agency Roscosmos is aiming to launch a lunar lander called Luna 25. It will touch down around the Boguslavsky crater, close to the Moon's south pole.

4 NOVEMBER 2021

The unmanned test flight Artemis 1 is expected to launch from the Kennedy Space Center on a mission lasting 25.5 days, six of which will be in retrograde orbit around the Moon.

JANUARY 2022

Japan's space agency JAXA is looking to send a lunar lander called the Smart Lander for Investigating Moon (SLIM). It will be the country's first attempt to land on the surface.

© NASA

© NASA

Top: Spacesuit engineer Kristine Davis wears a prototype Exploration Extravehicular Mobility Unit (xEMU) suit, which will be used for spacewalks

Left: An Artemis base camp is being developed to support longer expeditions on the lunar surface

of Zeus and Leto, and the Moon was among her charges. Her twin brother was Apollo, a name which has already graced lunar missions.

The agency's powerful Space Launch System (SLS) rocket will launch four astronauts aboard the Orion spacecraft for a multi-day journey to lunar orbit. Once there, two crew members will transfer to SpaceX's Human Landing System (HLS) for the final leg of their journey to the surface of the Moon. After approximately a week exploring the surface, they will board the lander for their short trip back to orbit, where they will return to Orion and their colleagues before heading back to Earth. The firm, fixed-price, milestone-based contract total award value is $2.89 billion (£2.05 billion).

"With this award, NASA and our partners will complete the first crewed demonstration mission to the surface of the Moon in the 21st century as the agency takes a step forward for women's equality and long-term deep-space exploration," says Kathy Lueders, NASA's associate administrator for human exploration and operations mission directorate. "This critical step puts humanity on a path to sustainable lunar exploration and keeps our eyes on missions farther into the Solar System, including Mars."

"This is an exciting time for NASA, and especially the Artemis team," says Lisa Watson-Morgan, program manager for the HLS at NASA's Marshall Space Flight Center in Huntsville, Alabama. "During Apollo, we proved that it is possible to do the seemingly impossible: land humans on the Moon. By taking a collaborative approach in working with industry while leveraging NASA's proven technical expertise and capabilities, we will return American astronauts to the Moon's surface once again, this time to explore new areas for longer periods of time."

SpaceX's Starship HLS, designed to land on the surface of the Moon, leans on the company's tested Raptor engines and flight heritage of the Falcon and Dragon vehicles. Starship includes a spacious cabin and two airlocks for astronaut moonwalks. The Starship architecture is intended to evolve to a fully reusable launch and landing system designed for travel to the Moon, Mars and other destinations in the Solar System.

With the powerful new SLS rocket, the Orion capsule, Starship HLS and the Gateway lunar outpost all planned, NASA and its commercial and international partners are returning to the Moon for scientific discovery, economic benefits and inspiration for a new generation.

2022

The Indian Space Research Organisation is planning its third lunar exploration mission, called Chandrayaan-3. It will involve a lander and small rover, but not an orbiter.

AUGUST 2023

Artemis II will be crewed. Those on board NASA's Orion spacecraft will perform a flyby of the Moon before returning to Earth from beyond low-Earth orbit for the first time in 51 years.

2023

Japanese billionaire Yusaku Maezawa is set to fly up to eight space tourists on a SpaceX Starship on a six-day tour around the Moon. Maezawa aims to fly to the ISS in December 2021.

OCTOBER 2024

NASA's Artemis III is due to land astronauts on the Moon in the south polar region. Two astronauts will be on the surface for about a week – but will the scheduled date be met?

2024

The Lunar Gateway is an international attempt to put a small space station in lunar orbit to make it easier to explore the Moon – and beyond – and carry out scientific experiments.

> "NASA WILL COMPLETE THE FIRST CREWED DEMONSTRATION MISSION TO THE SURFACE OF THE MOON IN THE 21ST CENTURY" KATHY LUEDERS

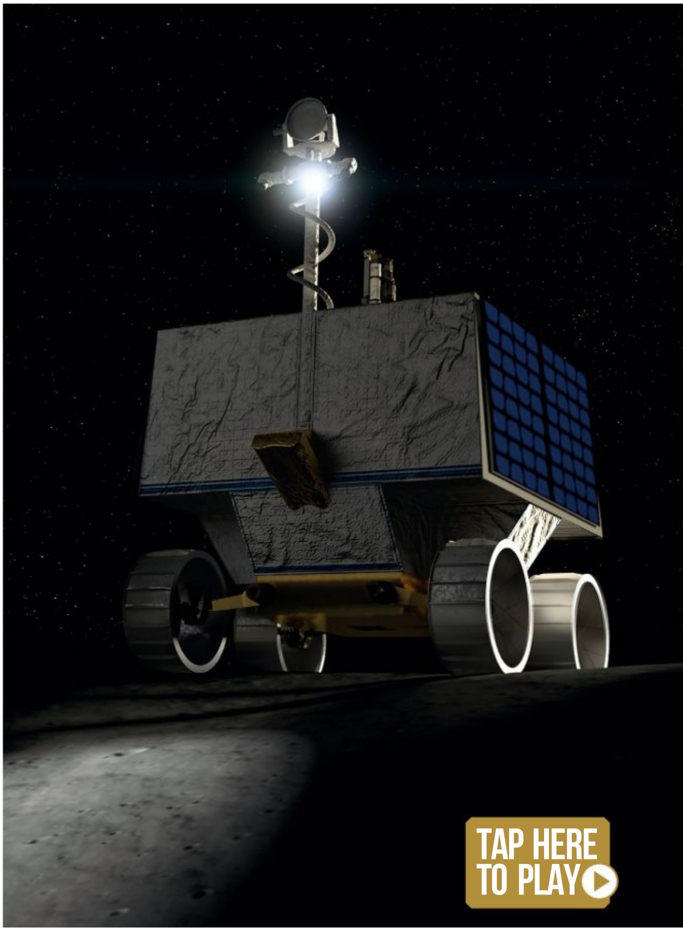
Eight countries initially signed the Artemis Accords, a set of guidelines surrounding the crewed exploration of the Moon. The UK, Italy, Australia, Canada, Japan, Luxembourg, Ukraine, the United Arab Emirates and the US are now all participants in the project, which aims to return humans to the Moon by 2024 and establish a crewed lunar base by 2030. Strangely, one NASA illustration of Gateway shows a Russian element.

Last year Japan said it will recruit astronauts for the first time in 13 years. Japan's Education and Science minister Koichi Hagiuda said the aim is to have a Japanese national on the Moon for the first time in the latter half of the 2020s.

Japan has seven astronauts in the Japan Aerospace Exploration Agency (JAXA), and three of them have already been to space. The Japanese government will seek applications in the latter part of 2021, and the selected group of astronauts may be part of Artemis. It's the first time since 2008 that Japan will be recruiting astronauts. "We will solicit applications around every five years from now on to maintain a group of astronauts," Hagiuda says. The project seeks to establish a "set of principles for space exploration, including lunar resource extraction".

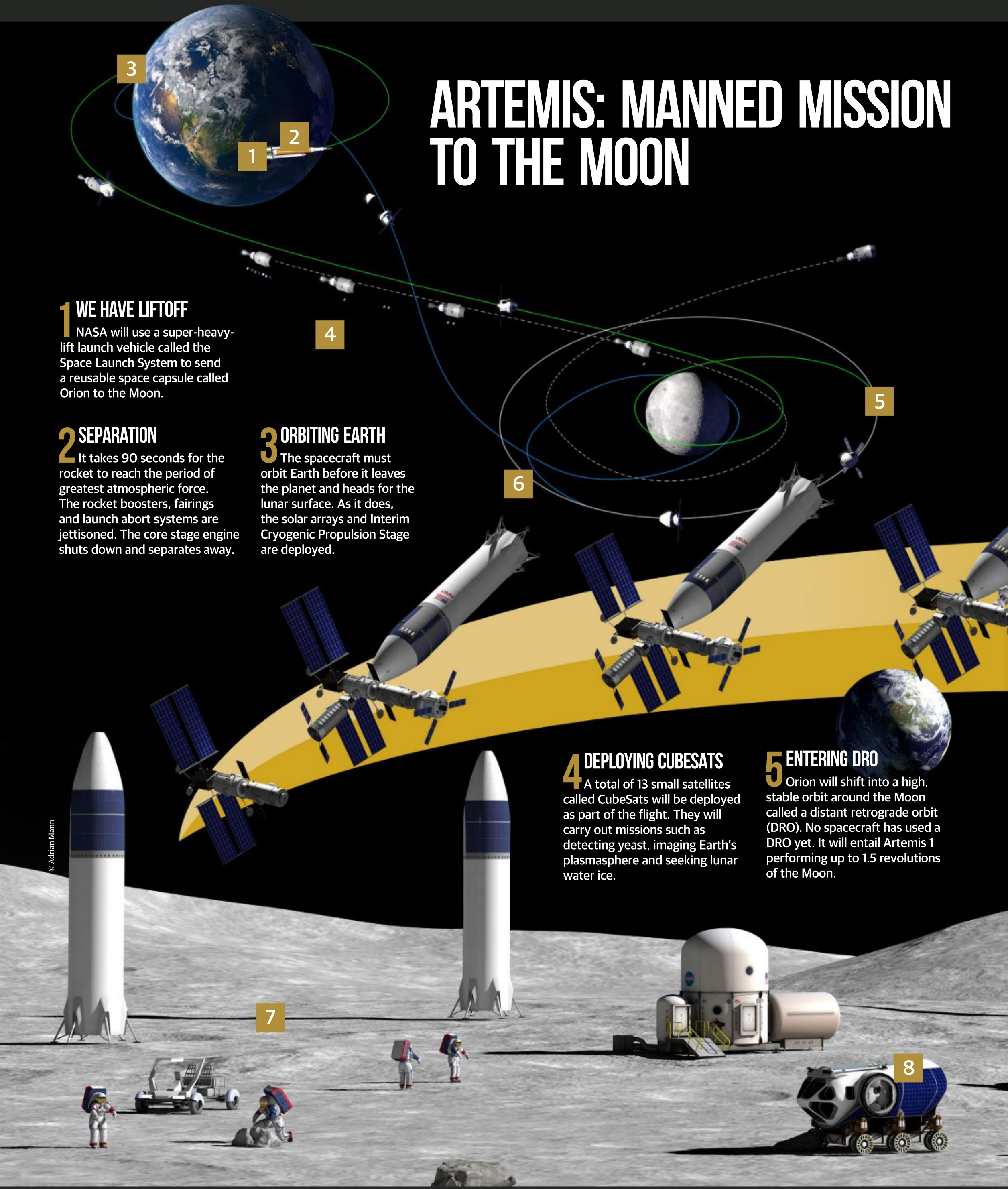
African and South American countries are so far absent, although Brazil has expressed an intent to join Artemis. Their economies may prevent their

Right: NASA's Volatiles Investigating Polar Exploration Rover (VIPER) will be sent to the south pole of the Moon, where it will be able to sample water ice ahead of a human landing



© NASA

ARTEMIS: MANNED MISSION TO THE MOON



1 WE HAVE LIFTOFF

NASA will use a super-heavy-lift launch vehicle called the Space Launch System to send a reusable space capsule called Orion to the Moon.

2 SEPARATION

It takes 90 seconds for the rocket to reach the period of greatest atmospheric force. The rocket boosters, fairings and launch abort systems are jettisoned. The core stage engine shuts down and separates away.

3 ORBITING EARTH

The spacecraft must orbit Earth before it leaves the planet and heads for the lunar surface. As it does, the solar arrays and Interim Cryogenic Propulsion Stage are deployed.

4 DEPLOYING CUBESATS

A total of 13 small satellites called CubeSats will be deployed as part of the flight. They will carry out missions such as detecting yeast, imaging Earth's plasmasphere and seeking lunar water ice.

5 ENTERING DRO

Orion will shift into a high, stable orbit around the Moon called a distant retrograde orbit (DRO). No spacecraft has used a DRO yet. It will entail Artemis 1 performing up to 1.5 revolutions of the Moon.

© Adrian Mann

© NASA

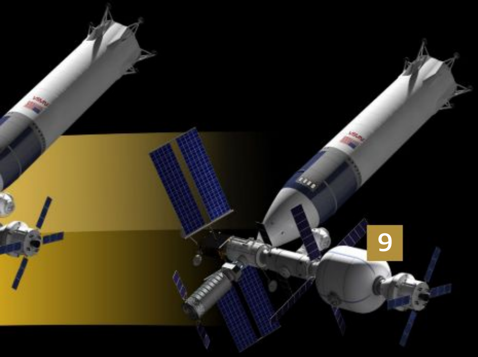
AR SCAN HERE

6 RETURNING TO EARTH

The spacecraft will leave DRO and head back to our planet, with the crew module separating from the service module ahead of entry into Earth's atmosphere.

7 A LUNAR OUTPOST

A small space station called Gateway is going to be put into orbit around the Moon. Not only will it allow for deep-space exploration, it'll make it easier to journey to the surface.

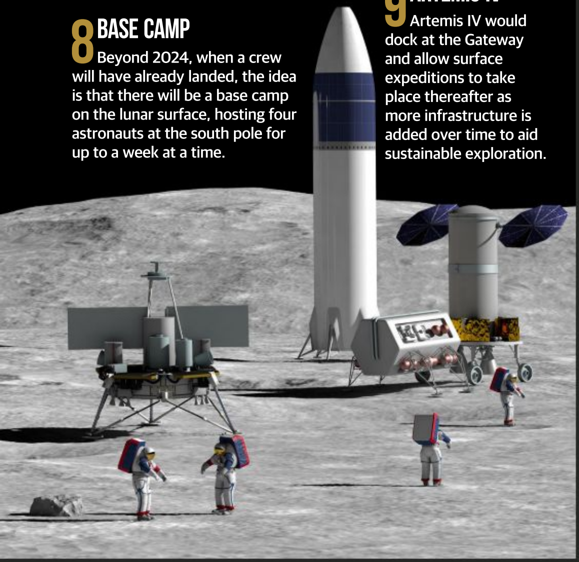


8 BASE CAMP

Beyond 2024, when a crew will have already landed, the idea is that there will be a base camp on the lunar surface, hosting four astronauts at the south pole for up to a week at a time.

9 ARTEMIS IV

Artemis IV would dock at the Gateway and allow surface expeditions to take place thereafter as more infrastructure is added over time to aid sustainable exploration.



© NASA

> "DURING APOLLO, WE PROVED THAT IT IS POSSIBLE TO DO THE SEEMINGLY IMPOSSIBLE: LAND HUMANS ON THE MOON" LISA WATSON-MORGAN

participation, however. India has a major space program despite its challenging economy, and may join, as Ukraine has recently done.

But the US is not the only country with its eyes on the Moon. China is very keen to promote its international achievements and find a place in space. The nation's economy is going from strength to strength, and it wants to follow on from its successful robotic lunar rovers. The new Chinese project has been named the International Lunar Research Station (ILRS). The European Space Agency (ESA) is also reported to be interested in collaborating with China.

The ESA's international relations administrator Karl Bergquist says: "We are following the Chinese lunar exploration plans very closely in order to see where our respective programmatic interests could meet, primarily the Chang'e-6, 7 and 8 missions, but also the ILRS initiative." Jan Wörner, the recently retired director general of the ESA, has previously suggested that many countries could collaborate to create a 'Moon village', perhaps the ESA nations, the US, China, Russia, India and Japan, which all have vibrant space initiatives.

In March, the heads of the Chinese and Russian space agencies signed a memorandum of understanding on cooperative construction of the ILRS. Zhang Kejian, head of the China National Space Administration (CNSA), and Dmitry Rogozin, general director of Roscosmos, signed the document during a virtual meeting on 9 March.

The ILRS is described as a comprehensive scientific experiment base built on the lunar surface or in lunar orbit that can carry out

Above: Phase 1 early Gateway with Power and Propulsion Element (left), Habitation and Logistics Outpost (centre foreground), and cargo spacecraft (centre background)

Below: An artist's rendition of an Artemis astronaut wearing the xEMU spacesuit and xPLS life-support backpack during an EVA on the Moon

multi-disciplinary and multi-objective scientific research activities, including exploration and utilisation, lunar-based observation, basic scientific experiments and technical verification and long-term autonomous operation. Statements from both Roscosmos and the CNSA underline that the project will be "open to all interested countries and international partners". If on the surface, the ILRS will likely be constructed at the lunar south pole.

China and Russia have previously signed agreements for cooperation on the Chang'e-7 and Luna 27 missions and a joint data centre for lunar and deep-space exploration. Chang'e-6, a polar sample-return mission, is scheduled for some point in 2023 or 2024. The later Chang'e-8 mission will be designed for in-situ resource utilisation and 3D-printing technology tests, as well as life science related to potential long-term stays on the Moon. These missions will form the robotic basis of the ILRS before expansion into a more long-term base. Meanwhile, Russia is preparing to launch its Luna 25, Luna 26 and Luna 27 lander missions across the 2020s.

The early stage ILRS would appear to consist of a number of discrete spacecraft, in contrast to a more complex, integrated program such as the International Space Station (ISS). China is also developing capabilities for deep-space human spaceflight. In May 2020 China tested a new spacecraft, and is also developing two separate super-heavy-lift launchers for space infrastructure and crewed missions. The Chinese space station Tiangong, with construction to begin soon, is planned to bring China expertise and experience in human spaceflight operations ahead of potential crewed lunar missions.

The return to the Moon could become a race with two factions - the China and Russia-led ILRS and the US-led Artemis program involving many other nations - in direct competition. But this time it's not just for glory and publicity, it's for mining rights, and that's where things get difficult.

This falls under international space law, but do lawmakers have the teeth to control the exploitation of the Moon? If mining becomes very profitable, which nations get to benefit, and how much? Will it be a lunar 'gold rush'? Russia has already criticised Artemis as being too US-centric, and the next space race could be one for profit.

The International Space Station has been a technical and political success since construction began, but will present-day international politics permit one multi-country base on the Moon? It's a distinct possibility if the funding can be defended. Or will we have two competitive bases?

Such programs may be easier in command economies than democratic ones. The space community will try again to bring the people of the world together, as it has for decades on smaller scales. Future moonwalkers may look back on Earth, our only home so far, and intensify the philosophy that we need to learn how to share it and look after it, provided national or regional greed does not take hold.

Ian Parker
Space science writer
Ian has been writing about space since 1985. He has reported on missions from the Kennedy Space Center, French Guiana and Kazakhstan.

TAP HERE TO PLAY

© NASA

Above: Testing of craft and systems is well underway at NASA

Below: A return to the Moon could see a resurgence of old technology, like Moon buggies

© NASA

RETURN TO THE MOON BY NUMBERS

3 MISSIONS
Artemis I, II and III will put astronauts back on the Moon

9
Number of countries who have signed the Artemis Accords

18
NASA has announced the Artemis astronaut group, called 'The Turtles'

8.8 MILLION
Thrust in pounds of NASA's Space Launch System

86 BILLION
Price tag of Artemis in USD

250,000
miles to the Moon

2
Artemis and ILRS programs may be competitive, or merged if politics allow

FEED YOUR MIND
www.howitworksdaily.com

AMAZING FACTS
COOLEST TECH
FREE 2 eBOOKS 2 POSTERS & WALLPAPERS
HOW ASTRONAUTS GET TO THE ISS
AR COVER!
HOW IT WORKS
WEIRD WORLDS BEYOND NEPTUNE
WIN ROBOT SPHERES WORTH £220
AR ZONE! SCAN HERE
ALL ABOUT YOUR DNA
MEET THE MOLECULE THAT MAKES YOU, YOU!
EMERGENCY SERVICE VEHICLES EXPLORED
THE CHEMISTRY OF YOUR COSMETICS
ANIMALS WITH SUPERPOWERS
HOW TO BUILD A HOUSE STEP-BY-STEP, BRICK-BY-BRICK
+ HYDROGEN EXPLAINED LIFE-SAVING CAR TECH WHAT IS
Featuring NEW augmented reality experience!
SCAN THE QR CODES TO SEE THE MAG COME TO LIFE!
Inside a clean-air plane
BUY YOUR ISSUE TODAY!
SCIENCE UP CLOSE
ILLUSTRATIONS
INSIDE GADGETS

HOW IT WORKS

Print and digital subscriptions available at
www.magazinesdirect.com/know3for3
Also available from all good newsagents and supermarkets

How It Works magazine @HowItWorksmag howitworks@futurenet.com howitworksmag

SAMPLE RETURN FROM TITAN

A new NASA Institute of Advanced Concepts study is looking at the surprising advantages of a mission to Saturn's moon

We've launched missions across the Solar System and studied an increasing number of diverse targets, from gas giants to asteroids. But so far we've only brought physical samples back from the Moon and a couple of asteroids, with a Mars sample return a long-held ambition for NASA. However, Titan has such good resource options it may make sample return surprisingly easy for such a distant target.

Titan is arguably the most interesting target in the Solar System. It's the tenth-largest body and has a dense atmosphere of mostly nitrogen and methane. A similar effect that makes the surface pressure of Venus crushingly high gives this small body an atmospheric pressure just slightly greater than Earth's, making it the only surface beyond Earth where you wouldn't need a spacesuit. The other thing this dense, cold atmosphere enables is a surface liquid cycle, giving Titan rain, rivers, lakes and seas like we see on our home planet, but rather than water they are methane.

Though not expected to have surface life, it's an example of a prebiotic planetary surface, deep frozen for posterity. Titan also has a subsurface water ocean, which like Europa and Enceladus offers the possibility of harbouring simple life in the depths. But it's not an easy place to reach. Pioneer 11 and Voyagers 1 and 2 have performed Saturn flybys, and the Cassini orbiter spent 13 years in orbit after a journey of almost seven years. Cassini also brought the Huygens lander, which touched down on Titan in January 2005.

But despite the distance, Titan has a selection of attributes which could make sample return surprisingly feasible, starting with landings. This year saw NASA perform another dramatic crane landing with Perseverance. NASA is forced to employ such a complex system because Mars has a thin atmosphere. It's enough to get in the way and generate entry heating, but not thick enough to significantly slow spacecraft down. Titan's thick atmosphere would enable a lander to shed orbital speed through atmospheric drag and make a soft landing with a parachute.

All this serves to reduce the mass that must be taken to Titan in the first place, but it's with propellant supply that Titan really shines. On Mars methane must be formed out of the atmosphere, but on Titan rocket fuel is actually falling from the sky and lying around in pools, ready to be pumped into fuel tanks.

For oxygen, water ice doesn't need to be carefully filtered from the soil, as it constitutes the whole planetary crust. A prospective mission could melt the ice with waste heat from a radioisotope thermoelectric generator before splitting it into hydrogen and oxygen, releasing the hydrogen and storing up the oxygen.

On Titan oxygen and methane can even be stored as liquids without refrigeration. When it comes to launching home, potentially with samples collected by NASA's nuclear-powered Titan quadcopter Dragonfly, the surface gravity is only 14 per cent of Earth's, making access to space somewhat easier. It may be some time before Titan samples are coasting back to Earth, but it could be sooner than you might think.

1 SATURN

Titan is the largest moon of Saturn, and the iconic Ringed Planet will loom large – clouds permitting – in Titan's sky.

2 METHANE LAKES

Titan's unique advantage is that methane exists on Titan as water does on Earth, so there are huge reserves of liquid methane handy for filling tanks.

3 WATER ICE

While methane takes the place of water on Titan, water ice takes the place of rock. The crust is formed of ice, which can be melted and split to produce oxygen.

4 DENSE ATMOSPHERE

Titan's atmosphere is made up of nitrogen, giving the small body slightly more surface pressure than Earth. Combined with low gravity, this makes Titan good for aerobraking and parachute landings.

5 DRAGONFLY MISSION

NASA is also working on the Dragonfly mission for Titan, a nuclear-powered drone to explore the surface. This could bring samples to a sample-return mission.

6 SAMPLE-RETURN LAUNCH PAD

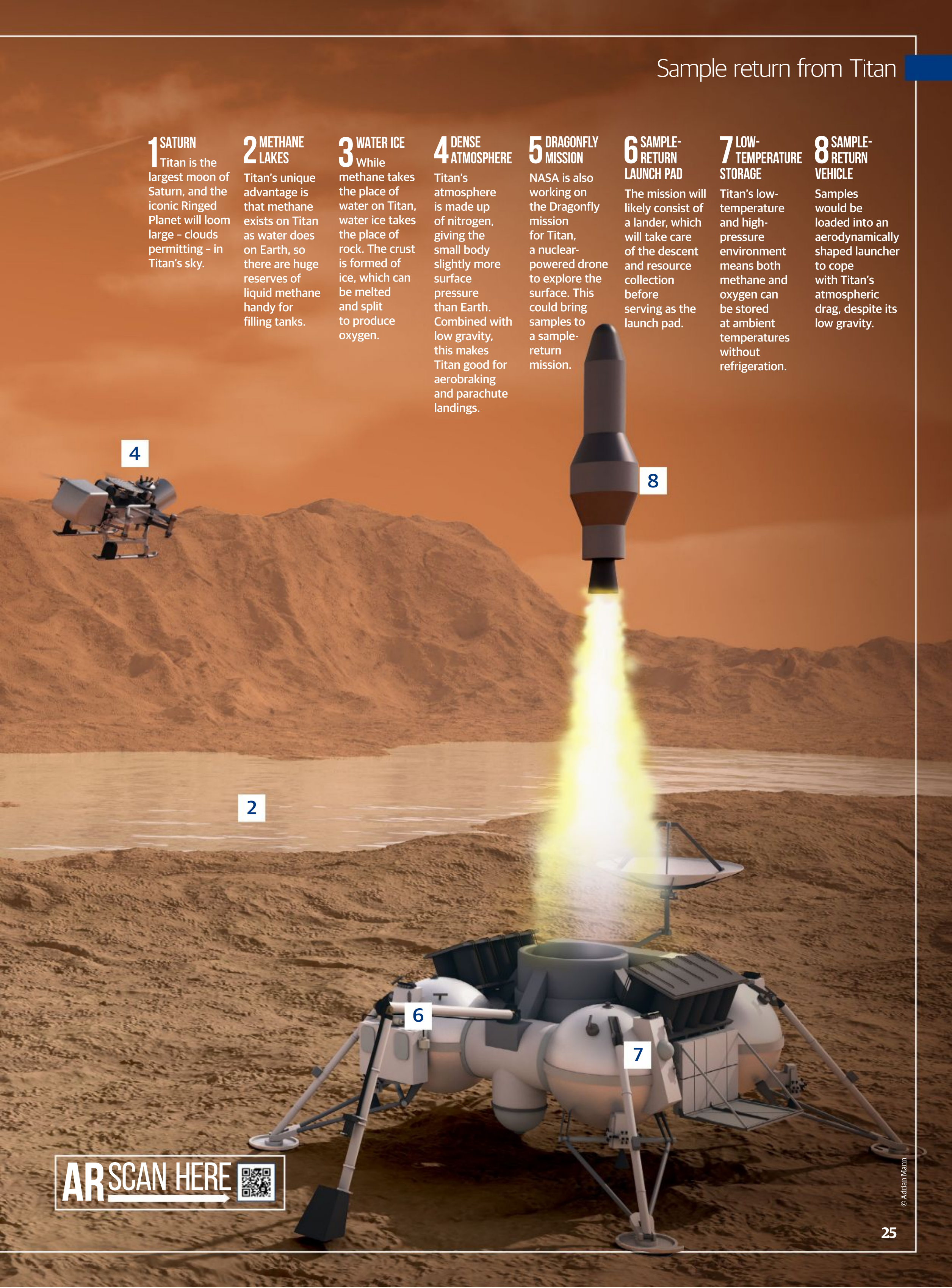
The mission will likely consist of a lander, which will take care of the descent and resource collection before serving as the launch pad.

7 LOW-TEMPERATURE STORAGE

Titan's low-temperature and high-pressure environment means both methane and oxygen can be stored at ambient temperatures without refrigeration.

8 SAMPLE-RETURN VEHICLE

Samples would be loaded into an aerodynamically shaped launcher to cope with Titan's atmospheric drag, despite its low gravity.



© Adrian Mann

INTERVIEW

© Robert Markowitz/NASA

BIO

Colonel Terry Virts

Former NASA astronaut Virts has spent over seven months in space on the ISS, where he captured the reality of his experience through photography. Virts has famously taken more photos from space than any other human, having taken over 300,000 spectacular images. He is also the author of the National Geographic photography book *View From Above*, as well as his latest book, *How to Astronaut*.

COLONEL TERRY VIRTS

"IT'S THE BIGGEST PROBLEM THAT WE'RE NOT WRITING ABOUT"

All About Space speaks with the former NASA astronaut about his time in space and his newfound 'cosmic perspective'

Interviewed by Daisy Dobrijevic

At what moment did you decide you wanted to become an astronaut?

When I was a little kid. The first book I read in kindergarten was about Apollo. Growing up I had pictures of the very first red white and blue 1974 F16, Space Shuttle Columbia and the Andromeda Galaxy. Those are the kinds of things I had all over my wall when I was a boy. When I was a kid I remember going to the Air and Space Museum and watching an IMAX movie called *To Fly!* and going: 'That is amazing. I want to be a pilot and an astronaut.' That IMAX movie really impacted me.

What was your least favourite part of your astronaut training?

Learning the Russian language was probably the hardest thing, but I loved it. I hated it and then I got over the hill and I loved it. The NBL [Neutral Buoyancy Laboratory] can be really fun and satisfying, and it can also be torture. I used to joke that it's the torture chamber, this giant building right in Ellington Field in Houston. The pool can not be fun because the suits are so bulky. In the early days it was really awful, then towards the end when I got good at it and I knew what I was doing it got a lot better. I remember after my first run I went and talked to Rex Walheim, the senior astronaut, and I was like, 'Rex, this is supposed to be fun?' He laughed and said, "Yes it sucks. It's terrible, but eventually it gets better."

Was there anything that your rigorous training didn't prepare you for in space?

It doesn't prepare you for the view - it's so spectacular. Words can't describe what it's like to see that with your own eyes. I've tried. I've written two books and I've got a kid's book coming out next year. I also directed a film called *One More Orbit* last year and helped make the IMAX movie *A Beautiful Planet*, so I'm trying to describe it and show it, but until you see it, the visual impact of looking out at Earth, it's really amazing.

Have you ever been left feeling that way with a particular view on Earth?

Earth is amazing; it's never-ending and there's so much to see down there. A place that's amazing is Antarctica. I had a chance to go there a few years ago, and the mountains are unlike anything I've ever seen. The Queen Maud Land mountains are just otherworldly. It's like you're on some planet in a different solar system.

Tierra del Fuego in southern South America is also an amazing place. The sunset I saw there was unbelievable. The blues and the pinks, I had never seen colours like that. I thought this can't be real. Tierra del Fuego was pretty spectacular.

There are a lot of spectacular places, but those two views just come to mind right away. Though there's still a lot of places I need to visit. I want to do a TV show where I go and visit the places that I saw from space.

Were you a keen photographer before you went into space?

Yes, I was. When I was a kid my parents got me a little Konica SLR camera and I learnt photography

Right: The northern lights seen dancing above Earth from the ISS

© Colonel Terry Virts

© Colonel Terry Virts

Left: Earth with the blue glow of the atmosphere around it

Below (left): Virts snapping photos from the ISS' Cupola observatory module

Below: A beautiful view of snowy mountains from above

© Colonel Terry Virts

© Colonel Terry Virts

on my own. In college I always had a camera around my neck. I think a lot of astronauts are like that. Some astronauts are camera people, and some are not. Everybody learns how to take pictures and everybody takes pictures in space, but some take lots like me and Don Pettit.

I take pictures on Earth too. Just yesterday I was out for a walk and took some photos of some ducks. I just take pictures all the time!

Have you had any close shaves in space?
Yes, by far the biggest deal was halfway through our mission. On my last flight, we had an ammonia alarm go off. It turned out to be a false alarm, but it was a really big deal for a day as we thought there was an ammonia leak in the station.

If there's a real ammonia leak it actually ends up killing the space station as it's uninhabitable, so we spent the day on a Russian segment with the hatch closed because they don't have ammonia. We were just staring at each other thinking, 'I guess the ISS is done... we'll hang out here for a few weeks'. By the end of the day they called the station and said, "It was a false alarm, but when you go back to the American segment wear your gas masks just in case, and take some samples just to be sure." That was probably the biggest close shave. We went through a phase for about a month where every day the alarms were going off with some caution or warning. It was a month of constant errors, and that got kind of old to be honest.

In the last year we've all been cooped up. Have you got any tips for dealing with isolation from your time on the ISS?
A year ago I wrote 10 lessons I learned about being stuck in space. When I was in space we had three cargo ships blow up back to back to back: an Orbital Cygnus, Russian Progress and SpaceX Dragon. We didn't know when we were coming back because they cancelled our return flight on the Soyuz until they could send our replacement crew. But they didn't want to launch our replacement crew until they figured out why the Progress blew up, because it's the same Soyuz rocket booster.

We were stuck, and we didn't know for how long. All of a sudden all of our work was done, so we had to add new tasks. We relocated the PMM [Leonardo Permanent Multipurpose Module], which was really fun. That was a really cool task to rearrange the space station. It was a big job too. We weren't supposed to do that, but we did.

The ten lessons I learned were: give yourself a schedule - don't just get lazy and watch Netflix every night, which is what I'm doing now. Keep on exercising, as exercise is very important. Don't watch the news 24/7. Every day we would get together and share what we had heard on the news, but it wasn't all day long. There's so much bad news right now, and so you have to moderate the news intake. Do something creative. For me, I was like, 'You know what, I've got the rest of my life on Earth. I'm going to take advantage of this.' I took a lot of pictures and I shot a lot of scenes for *A Beautiful Planet*.

Don't worry about things you can't control. I can't control COVID, so it doesn't do any good worrying about it. Just focus on what you can do. The most important thing is keep your attitude up. We had a good attitude, and we had a bet going as to when we were going to go back to Earth and when the next guys would launch. We all said 'we're here, we have the rest of our lives on Earth, so let's make the most of it'. Those are a few of my top-ten ways to handle isolation.

What was your favourite chapter to write in your book *How to Astronaut*?

The survival chapter was really fun because it brought back a lot of memories. The original chapter was two or three times as long. I started remembering all of these details from when I was 17 years old at the Air Force Academy and when I was 20 years old at the French Air Force Academy. I remembered all of these things from a long time ago that I had forgotten about. It's really fun to write that down.

There's also a chapter about the effects of carbon dioxide and the competition we had with a paper bag. We were just sitting around breathing into this paper bag, and you're sweating, you turn purple and your heart starts racing really fast. These are carbon dioxide symptoms and you need to know them. It actually happened to me in space two times: once on the shuttle and once on the station. I got in a carbon dioxide bubble and I had all those symptoms. But it was just funny how it turned into this competition with a paper bag.

How did you find writing your new book *How to Astronaut* differed from your picture book *View From Above*?

I wrote *View From Above* right after I left NASA. I retired, had my last day and then I was home. I would set the alarm every day, and by 08:00 I was typing away on my laptop. I would write a chapter, then my brain was full. I would go to the pool and have a beer, then set my alarm. Then the next day at 08:00, I was writing again. I wrote a chapter a day and took Sunday off, and I had the whole book written within two weeks.

A few years later I wrote *How to Astronaut*. I was travelling a lot because I was doing a lot of speeches and events for my day job. I couldn't just set my alarm and start writing because I was always on the road. A lot of that book was written on aeroplanes. I found them to be a great place to write because you're just stuck for a couple of hours, so I would just get my laptop out and start writing. Half of *How to Astronaut* or more was actually written on aeroplanes.

I was so happy about that book because I had two goals with it. I wanted people to laugh and say wow! Whenever I've taken part in an interview about the book, everybody has had that reaction, so I'm really happy about that.

Would you say you've gained a new perspective of Earth after being in space?

I think so, yes. People ask, 'How did you change?' I've thought about this, and I think the way it changed me is I'm less of a black-and-white person. The older you get, the more wisdom you have. You think that there's probably two sides to everything, and you really should look at the data before you come to a conclusion.

A short film that we made last year was called *Cosmic Perspective*. It was about how space photography has changed humanity. We used to be stuck on Earth. Everything was two dimensional, everything was north, south, east and west, right? Then once we started flying, all of a sudden there was this third dimension.

Now that we have Hubble and these telescopes that are really looking in four dimensions, they're not only seeing things that are far away, they're seeing things that are really old, you know, billions of years old.

Space photography has changed everything. People like you and me just grew up with it, like that was normal. One of the pictures I had when I was younger was from Viking, which was the first American lander on Mars. 100 years ago we barely had aeroplanes, so it's amazing how quickly our perspectives have changed.

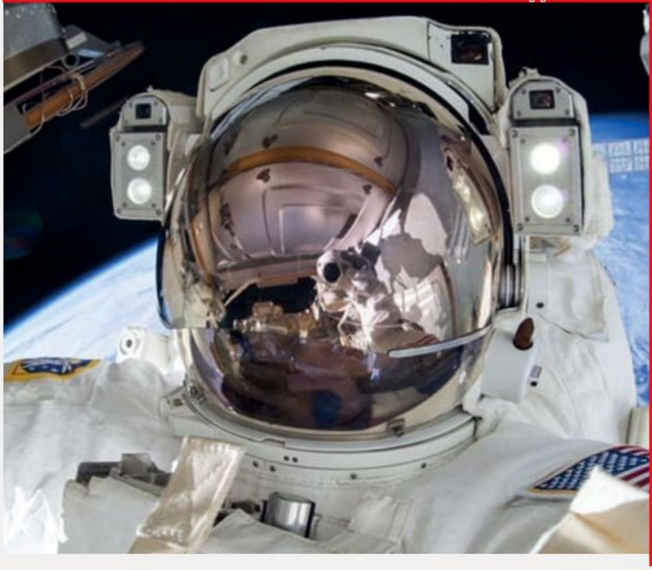
Do you think space has commercialised now it seems that everyone is having a go?

The problem is that everyone's having a go, and there are too many satellites being launched into orbit. Many of them are never going to come back down, so they're there permanently as debris.

It may be fine for the next few years, but a century from now and ten centuries from now they're still going to be in orbit. Talk about leaving climate change, we're leaving the space environmental problem for generations to come, and I don't think that's cool. I think that's something that needs to be addressed, and no one's talking about it.

It's a problem for astronomers, it's a problem for humanity. It's the biggest problem that we're not writing about.

> "THE MOST IMPORTANT THING IS KEEP YOUR ATTITUDE UP"



Right: Virts floating above Earth on one of his three extravehicular activities

© Colonel Terry Virts

© Tobias Roetsch

WORLDS WITHOUT SUNS

Astronomers are still on the hunt for rogue planets, but what can they tell us about the layout of our cosmos?

Reported by Colin Stuart

When we think about planets, a star usually comes as part of the package. After all, where would Earth be without the Sun? Imagine Luke Skywalker's home planet of Tatooine without its twin suns, or Superman without Rao, the red supergiant around which Krypton spun. Yet you'd be wrong to imagine that planets are never starless. Astronomers have already found swarms of rogue planets - worlds wandering the open chasm of space alone.

As far as we know, planets always start off with stars. They are the leftover fragments from star formation, the offcuts that you'd throw away in a skip if you were building a house. A cloud of gas and dust that was otherwise minding its own business may begin to contract if it's hit by a shock wave from an exploding star. As the cloud compresses, gravity takes over and bundles it into an ever-smaller space until fledgling stars ignite inside.

The shrinking cloud begins to spin faster and faster, flinging leftover gas and dust into discs around new stars. Gravity continues its work here, too. Dust grains merge into lumps the size of golf balls, which continue to snowball until they reach a kilometre or so across.

Astronomers call these planetary building blocks planetesimals. Close to the star they are made of metals - the only materials with high enough melting points to stay solid in the face of the inferno. Further out - beyond an imaginary boundary called the ice line - temperatures plummet below freezing and the planetesimals take the form of frigid lumps of water, ammonia and methane ices. That's why we have rocky planets close to the Sun and ice giants the furthest out.

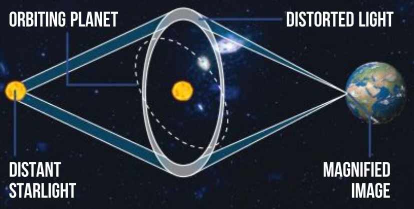
Looking at the Solar System today, it seems a somewhat serene place. Yet this relative calmness belies the cataclysmic pinball machine that it used to be. Jupiter formed further from the Sun before migrating inwards, scattering many of the asteroids like a flock of pigeons. Uranus and Neptune moved outwards, and may

HOW TO FIND A ROGUE PLANET

GRAVITATIONAL MICROLENSING

Microlensing is the distortion and magnification of a star's light when another object passes in front of it and bends the path of light passing near it through gravity. It's been successfully used to find exoplanets orbiting other stars, but can also be used to detect interstellar planets, allowing astronomers to estimate how common they are. Microlensing events by interstellar planets tend to be one-offs, so it's hard to learn much about the planets themselves.

MICROLENSING AT WORK



DIRECT IMAGING

The direct detection of interstellar planets relies on long-exposure surveys of large areas of the sky looking for brown dwarfs and other faint objects. Infrared surveys are particularly useful, since many of these objects emit more radiation as heat than they do as light. Surveys often target areas of recent star formation, where objects are likely to be at their youngest, and therefore hottest and brightest.

© Tobias Roetsch

ARE ROGUE PLANETS IDEAL FOR LIFE?

Pretty much all life on Earth is dependent on the Sun to survive, so it might seem strange to imagine life thriving on planets lost in the interstellar darkness. But researchers say we shouldn't write off rogue planets.

As early as 1999, David J. Stevenson of the California Institute of Technology argued that even small rogue planets expelled from their solar systems could sustain a hydrogen-rich atmosphere and a warm surface for long enough for life to evolve, thanks to the radiation of energy left over from their formation. This idea is clearly confirmed by the discovery of gas giants like PSO J318.5-22, which pumps out enough energy to vaporise iron.

Of course, any life that evolved in the hot atmosphere of a rogue gas giant would be very different from what we see on Earth – conditions might prevent life from gaining a foothold at all, and would almost certainly stop it at the level of bacteria-like organisms that could float among the clouds.

But more solid Earth-like worlds with geological activity driven by escaping heat could also have the potential to sustain life on or beneath their surfaces, perhaps similar to the bacteria associated with 'hot rocks' and subterranean water channels on Earth. With photosynthesis out of the question due to a lack of sunlight, the 'primary producers' at the base of any alien food chain would have to find another chemical means of generating energy, perhaps by consuming carbon from the rock itself.

Perhaps the most promising home for life in interstellar space, however, would not be on a rogue planet itself, but on its moons. Here tidal forces might create an environment similar to those seen on several moons in our own Solar System, with a deep ocean of liquid water, heated from below by volcanic activity and shielded from space by a solid, icy crust. Such an interstellar ocean could offer hospitable conditions for the development of fairly advanced aquatic life forms.

have even swapped order. At least that's according to the Nice model, which is named after the city in France where it was devised. It says that the Solar System started off in a different configuration before evolving into the set-up we see today.

Crucially, when planetary scientists run computer simulations of the Solar System's evolution, they recreate the modern planetary set-up more often when they include a fifth giant planet from the outset. There's more evidence for extra planets, too. We already think, for example, that a Mars-sized planet called Theia careened into the Earth just after our planet formed. The resulting surge of debris into space eventually coalesced to form the Moon.

But if there really was a fifth giant planet patrolling the Solar System where did it go? After all, there are clearly only four giant planets now. Astronomers conveniently say that it was discarded in a gravitational tussle with its siblings, or perhaps picked off by the gravitational pull of a star that buzzed close by. Maybe it ended up marooned in the darkest depths of the Solar System. That would certainly fit with recent ideas about a so-called Planet Nine lurking far beyond Pluto, the dwarf planet that we used to regard as the ninth planet.

Yet it could have been ejected from the Solar System entirely. It's a notion that once may have seemed far-fetched, but is gaining significant ground. After all, we've recently seen jettisoned visitors from other solar systems in the form of 'Oumuamua and Comet Borisov.

While it would take considerably more force to orphan an entire planet, the fact that we seem to have lost one from our own Solar System bolsters the argument. Stars could also lose their gravitational grip on outer planets as they die. The Sun will one day become a red giant and lose mass as it sheds its outer layers. This could cut the invisible tether to Neptune, irretrievably sending it out into the universe like a child accidentally letting go of a helium balloon.

It's therefore no surprise that there are vagrant planets trekking through the void. Though given their relatively small size, considerable distance from us and the fact they are not illuminated by a star, it's a wonder we've been able to spot them at all. It's only possible thanks to a clever technique called gravitational microlensing.

We often think of gravity as a pull – that the Sun pulls on the Earth, and that's why we orbit around it. It's certainly the way Isaac Newton thought about gravity. Yet over a century ago Albert Einstein replaced this simple notion with the idea that gravity is the result of curved space. A heavy object like the Sun warps the fabric of space around it, creating a divot in the universe that astronomers call a gravitational well. Earth is caught in this cosmic trap, which is why we're stuck in orbit around the Sun.

Any light travelling across the universe will be forced to alter its path if it encounters the curved space around a local heavy object. Rays of light are bent around it, just as a lens in a telescope bends light. The result is the same: the light gets magnified. If an otherwise-invisible rogue planet passes in front of a distant light source, we can tell it's there by the way it temporarily amplifies that background light.

Below: Another planet slammed into Earth when it was young, an event thought to have formed the Moon

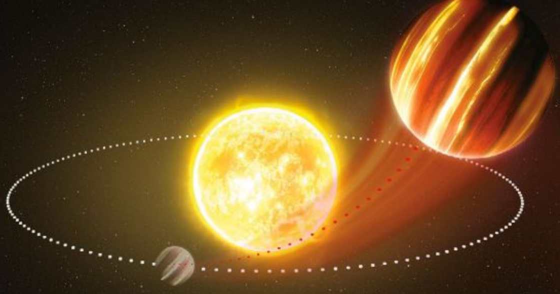
© Tobias Roetsch

HOW ROGUE WORLDS ARE MADE

Astronomers have put forward a variety of theories to explain how planets could end up drifting through interstellar space

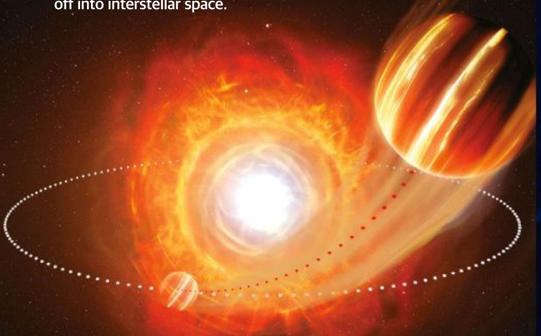
1 THEY'RE KICKED OUT OF THEIR SYSTEM IN A PLANETARY COLLISION

Not all planetary systems are as neatly ordered as our own, and they all evolve over time. If a Jupiter-mass planet had a close encounter with a neighbour, the smaller planet could find itself ejected from orbit around its star.



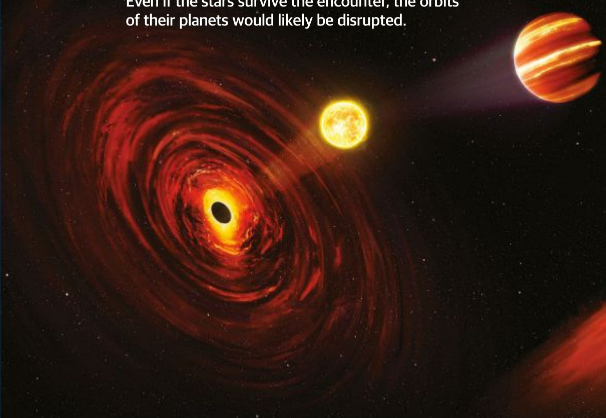
2 THEY'RE EJECTED BY A SUPERNOVA EXPLOSION

When the most massive stars reach the end of their lives, a spectacular explosion sheds most of their mass and drastically reduces their gravity, potentially cutting loose any orbiting planets to fly off into interstellar space.



3 THEY'RE THROWN OUT BY A COLLISION WITH A STAR OR BLACK HOLE

Close encounters and collisions of stars and stellar remnants, such as black holes, are inevitable over astronomical timescales, happening often in the densely packed clusters where stars are born. Even if the stars survive the encounter, the orbits of their planets would likely be disrupted.



4 THEY FORM ALONE FROM A DISC OF DUST AND GAS

Computer models and observations both show that planet-like objects with more mass than Jupiter, but less mass than a brown dwarf, can form independently out of knots of gas and dust in the same stellar nurseries as stars. Perhaps some rogue planets never had a host at all.

> "JUPITER FORMED FURTHER FROM THE SUN BEFORE MIGRATING INWARDS, SCATTERING MANY OF THE ASTEROIDS"

© Tobias Roetsch

WANDERING WORLDS WE'VE FOUND SO FAR

CHA 110913-773444

Distance away:
529 light years

Discovery method:
Direct observation

Constellation: Chamaeleon

Discovered in 2004, Cha 110913-773444 has the mass of about eight Jupiters, making it a candidate interstellar planet. Infrared observations show that it is surrounded by a faint disc of planet-forming material – perhaps moons in formation?

WISE 0855-0714

Distance away:
7.27 light years

Discovery method:
Direct observation

Constellation: Hydra

Discovered in 2014 using the Wide-field Infrared Survey Explorer, this small object is a little over seven light years away. With a low surface temperature, it's either a cold, low-mass brown dwarf or an interstellar planet on our cosmic doorstep.

PSO J318.5-22

Distance away:
80 light years

Discovery method:
Direct observation

Constellation: Capricornus

PSO J318.5-22 is the best studied rogue planet so far, with a tightly constrained mass and age that indicates it's undoubtedly a planet rather than a brown dwarf. It is about 80 light years away and was discovered in 2013.

CFBDSIR 2149-0403

Distance away:
130 light years

Discovery method:
Direct observation

Constellation: Aquarius

CFBDSIR 2149-0403 seems to be part of the AB Doradus Moving Group, a group of stars 50 to 120 million years old. With a surface temperature of 430 degrees Celsius (806 degrees Fahrenheit), its mass is likely four to seven Jupiters.

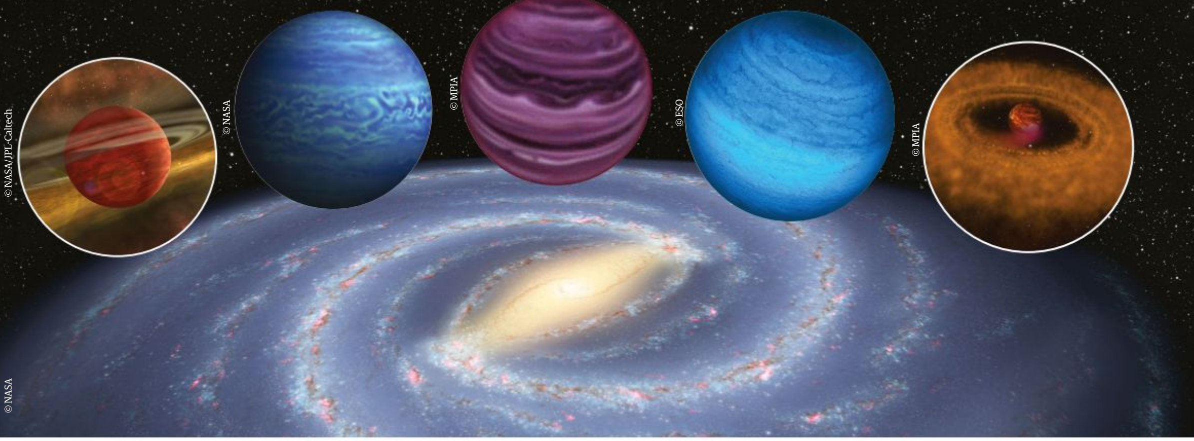
OTS 44

Distance away:
554 light years

Discovery method:
Direct observation

Constellation: Chamaeleon

This faint, young object has a mass between 6 and 17 Jupiters, putting it on the boundary between brown dwarf and planet. Excessive infrared radiation from its surroundings suggests it's shrouded by a disc of planet-forming material.



© NASA/JPL-Caltech

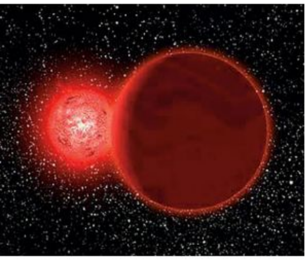
© NASA

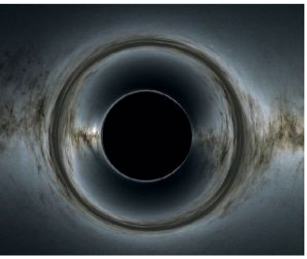
© MPIA

© ESO

© MPIA

© NASA





Left: A star passing close to another solar system could rip out a rogue planet

Bottom left: Planetary-mass lenses could also be miniature black holes instead of rogue planets

© Michael Osadciw/University of Rochester

© NASA

The technique does have its drawbacks, however. The alignment between the rogue planet – the lens – and the background light source is always temporary and fleeting. It typically lasts between a few hours and a few days. After that we're never going to see it again, and so we only have that single measurement to go on. Fortunately, the duration of the event does tell us something important: mass. The lighter the lens, the shorter the magnification spike lasts.

It's been over ten years since Japanese scientists used the Optical Gravitational Lensing Experiment (OGLE) to find rogue planets. They observed 50 million stars in the Milky Way and found just 474 microlensing events. Only ten turned out to be consistent with objects with planetary masses. But just because an object has the same mass as a planet doesn't make it a planet – it could be a miniature black hole with the same mass. More plausibly it could be a failed star called a brown dwarf. They start off with a mass considerably higher than Jupiter's, but could cool and shrink.

Once you get down to objects with masses more similar to Earth's, it's harder to argue that they aren't rogue planets. In September 2020, for example, astronomers announced the discovery of the smallest ever rogue planet candidate – one with a mass roughly equal to Earth.

We may even have found rogue planets in other galaxies. In 2018 astronomers at the University of Oklahoma looked at a galaxy that was lensing light from the distant quasar RX J1131-1231. Irregularities suggested the presence of an enormous number of objects with masses between the Moon's and Jupiter's. The total number of such objects in that galaxy could top 1 trillion. While some could be black holes or brown dwarfs, it's likely that a significant proportion are rogue planets.

Even in our own galaxy there could be as many as 50 billion starless planets, according to a 2019 study that looked into how frequently worlds get kicked out of their home solar systems. That's why finding rogue planets is about more than just collecting cosmic curiosities. Working out the

© NASA

ratio of vagabond worlds to stars in the Milky Way is an important part of understanding how solar systems form and evolve.

Soon there will be a step change in our ability to complete this celestial survey. In 2025, NASA plans to launch the Nancy Grace Roman Space Telescope. When Roman reaches space, it will carry with it a mirror 2.4 metres (7.9 feet) in diameter, equal in size to the Hubble Space Telescope's. However, it will have a field of view much greater than its cousin, allowing it to observe an area one hundred times wider than Hubble can.

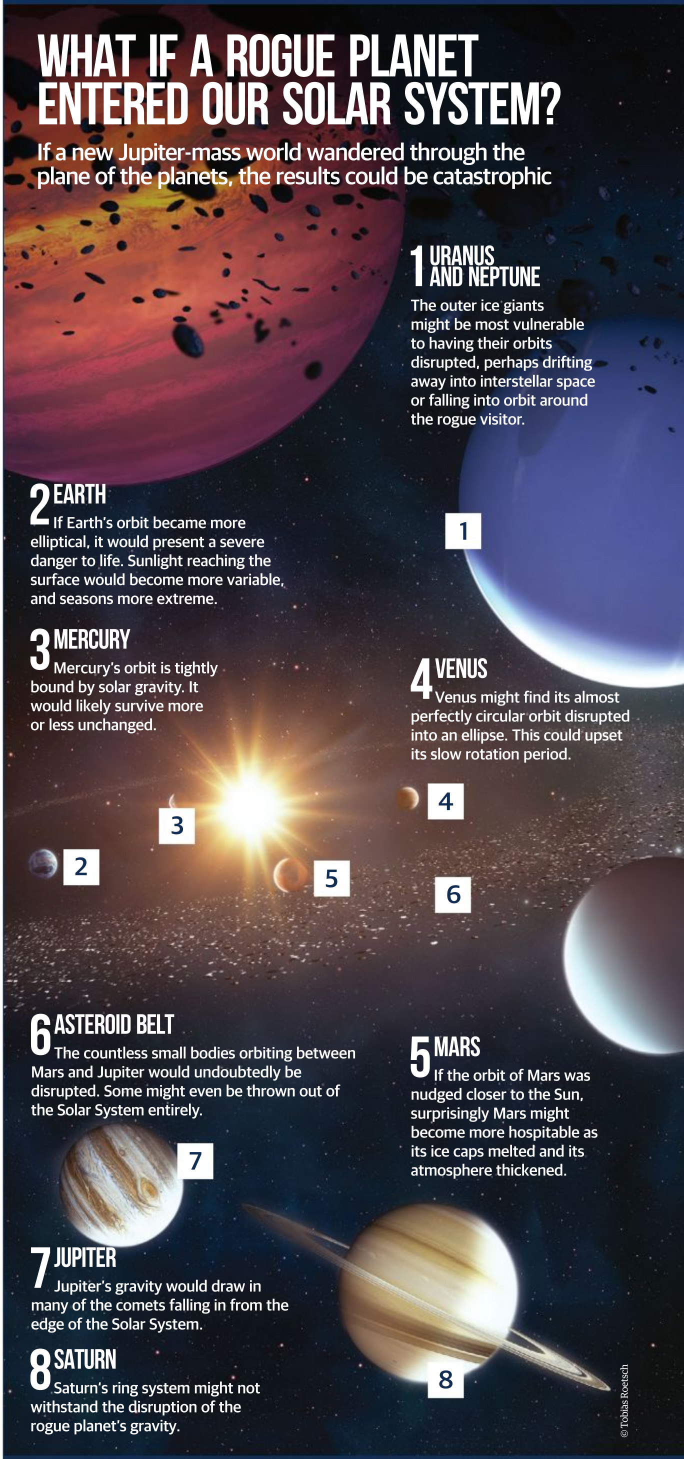
Roman is designed for many purposes, including helping to decipher the twin puzzles of dark matter and dark energy – the mysterious entities that bind a galaxy together and push galaxies apart respectively. Yet it will also be able to use microlensing to search for rogue planets – or free-floating planetary-mass objects, to give them their full name. Roman is sensitive enough to discover rogue planets that range in mass from Mars, at ten per cent of Earth's mass, all the way up to 100 Earth masses. In doing so it will provide an estimate of the number of rogue planets in the Milky Way that is ten times more accurate than the data we currently have.

Only then will we have the tools to understand how our Solar System came to look the way it does, telling us something important about what kinds of planetary systems to search for if we want to find other life-supporting planets in this vast and complicated universe.

Above: The Roman telescope, due for launch in 2025, will search for rogue planets

Colin Stuart
Science and technology journalist
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.

> "WORKING OUT THE RATIO OF VAGABOND WORLDS TO STARS IN THE MILKY WAY IS AN IMPORTANT PART OF UNDERSTANDING HOW SOLAR SYSTEMS FORM"



WHAT IF A ROGUE PLANET ENTERED OUR SOLAR SYSTEM?

If a new Jupiter-mass world wandered through the plane of the planets, the results could be catastrophic

1 URANUS AND NEPTUNE

The outer ice giants might be most vulnerable to having their orbits disrupted, perhaps drifting away into interstellar space or falling into orbit around the rogue visitor.

2 EARTH

If Earth's orbit became more elliptical, it would present a severe danger to life. Sunlight reaching the surface would become more variable, and seasons more extreme.

3 MERCURY

Mercury's orbit is tightly bound by solar gravity. It would likely survive more or less unchanged.

4 VENUS

Venus might find its almost perfectly circular orbit disrupted into an ellipse. This could upset its slow rotation period.

6 ASTEROID BELT

The countless small bodies orbiting between Mars and Jupiter would undoubtedly be disrupted. Some might even be thrown out of the Solar System entirely.

5 MARS

If the orbit of Mars was nudged closer to the Sun, surprisingly Mars might become more hospitable as its ice caps melted and its atmosphere thickened.

7 JUPITER

Jupiter's gravity would draw in many of the comets falling in from the edge of the Solar System.

8 SATURN

Saturn's ring system might not withstand the disruption of the rogue planet's gravity.

© Tobias Roetsch

SUBSCRIBE TODAY AND GET THIS BOOKZINE BUNDLE

NEW
HOW IT WORKS BOOK OF
SPAC
Everything you want to know about the un
OVER 1000 AMAZING FACTS
SOLAR SYSTEM
EXPLORATION
UNIVER
NEW
DISCOVER HOW HUMANITY REACHED BEYOND EARTH
SPACE EXPLORATION
MARS
EVERYTHING YOU NEED TO KNOW ABOUT THE RED PLANET
SPACE
RTH
COVERED
UGH THE INCREDIBLE WORLD WE LIVE IN
LIMITED TIME OFFER!

NEW!

Reasons to subscribe…

- You'll never miss an issue!
- It's delivered direct to your door
- Brilliant value – great savings on the cover price
- Special subscriber covers

APOLLO ANNIVERSARY
BACK TO THE MOON
MANY NATIONS ARE INTERESTED IN RETURNING TO THE MOON TO EXPLORE AND MINE IT

Subscribe now

www.magazinesdirect.com/aas/bundle21

or call 0330 333 1113 and quote BT16

£10.65 every three months

13 issues of **All About Space** in print over 12 months

SAVE 37%

£11.90 every three months

13 issues of **All About Space** in print and digital over 12 months

SAVE 60%

£7.15 every three months

13 issues of **All About Space** in digital

Bundle not included with digital

SAVE 44%

*Terms and conditions: Offer closes 31 July 2021. Offer open to new UK subscribers only. Pricing is guaranteed for the first 12 months and we will notify you in advance of any price changes. Please allow up to six weeks for delivery of your first subscription issue, or up to eight weeks overseas. Your gift will be delivered separately within 60 days after your first payment has cleared. Gifts only available to subscribers on the UK mainland. Gift not available with a digital subscription. The full subscription rate is for 12 months (13 issues) and includes postage and packaging. If the magazine ordered changes frequency per annum, we will honour the number of issues paid for, not the term of the subscription. For full terms and conditions, visit **www.magazinesdirect.com/terms**. For enquiries please call: +44 (0) 330 333 1113. Lines are open Monday to Friday 9am to 5pm UK Time or e-mail: **help@magazinesdirect.com**. Calls to 0330 numbers will be charged at no more than a national landline call, and may be included in your phone provider's call bundle.

ON BOARD THE VOMIT COMET

You'd better have a strong stomach: in space, everyone can hear you spew

Reported by Ian Evenden

Earth has a problem, at least if you want to train astronauts. It's called gravity, and while useful for things like attaching your feet to the ground, it's an inconvenience when you need to acclimatise people to weightlessness. So what do you do? If you're a national space agency, you set up a special flight that takes advantage of free fall to simulate the weightless experience.

In order to simulate a feeling of weightlessness like astronauts experience once free of Earth's gravity, the aircraft flies a particular flight path. It climbs at an angle of 45 degrees to altitude before nosing over and descending at 30 degrees in a parabolic path relative to the centre of the Earth, using just enough engine thrust to cancel out the drag of the aircraft moving through the air. During certain parts of the flight, the aircraft and all aboard it are in free fall and experience weightlessness. This begins while the craft is still ascending, continuing while it passes the peak of its climb and begins to descend, until the pilot is forced to pull up on the stick to climb again and avoid hitting the ground. For each parabola, passengers and crew experience around 25 seconds of weightlessness, and a flight is likely to carry out 40 to 60 such manoeuvres.

The idea goes back to 1950, when it was proposed by German brothers Heinz and Fritz Haber, a physicist and aerospace engineer respectively. They had been taken to the US as part of Operation Paperclip at the end of World War II, where they undertook pioneering research in space medicine and worked with Wernher von Braun. Heinz would also collaborate with Shih-Chun Wang, a Chinese-American doctor studying nausea in astronauts for NASA, on the creation of the Vomit Comet.

The aircraft is a perfectly normal one, apart from having a large, open space inside for passengers to float in. Estimates for how many will be affected by nausea vary, with around 45 per cent suffering some symptoms. In space these rarely last more than 72 hours as the body adapts to its new surroundings. Blue Origin's Jeff Bezos, speaking at the 2017 Space Symposium in Colorado Springs, claimed it wasn't a problem for training flights: "[Astronauts] don't throw up right away," he said. "We're not going to worry about it… It takes about three hours before you start to throw up. It's a delayed effect."

Former Reduced Gravity Research Program director John Yaniec gave a simple breakdown of who was most likely to vomit during a parabolic flight during a 1999 interview: "I don't really keep any stats," he said. "But it amounts to a rule of thirds: one-third violently ill, the next third moderately ill and the final third not at all." Matt Gohd, CEO of the Zero Gravity Corporation, the company currently tasked with flying parabolic flights both for NASA and paying customers, disagrees, claiming the flights have only a "one per cent occurrence" of the worst symptoms.

> "THE ONLY THING THAT I CAN LIKEN IT TO IS A REALLY BIG ROLLER COASTER WHERE YOU GET SOME AIR TIME"
>
> EMILY CALANDRELLI

©Getty

© NASA

Right: Physicist Stephen Hawking enjoys zero gravity during a flight aboard a modified Boeing 727 owned by the Zero Gravity Corporation

TAP HERE TO PLAY

THE VOMIT COMETS

CONVAIR C-131 SAMARITAN

Top speed:
472 kilometres (293 miles) per hour
Max altitude:
7,470 metres (24,500 feet)
Size of plane:
24 metres (79 feet)
Weight of plane:
13,294 kilograms

© Public Domain

BOEING KC-135 STRATOTANKER

Top speed:
933 kilometres (580 miles) per hour
Max altitude:
15,240 metres (50,000 feet)
Size of plane:
41.5 metres (136 feet)
Weight of plane:
56,245 kilograms

Source: Wiki Commons © Jim Evans

MCDONNELL DOUGLAS C-9

Top speed:
933 kilometres (580 miles) per hour
Max altitude:
11,278 metres (37,000 feet)
Size of plane:
36.4 metres (119 feet)
Weight of plane:
27,079 kilograms

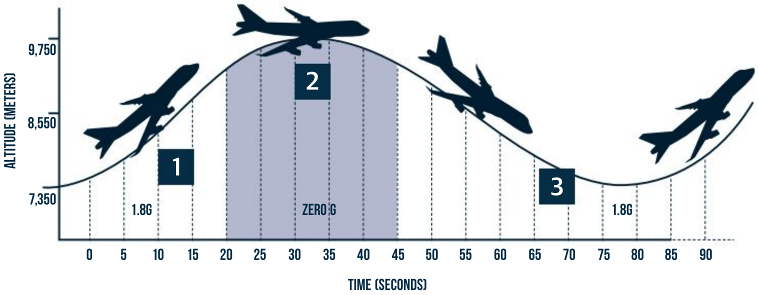
© NASA

BOEING 727-200

Top speed:
370 kilometres (597 miles) per hour
Max altitude:
12,801 metres (42,000 feet)
Size of plane:
46.6 metres (153 feet)
Weight of plane:
97,650 kilograms

Source: Wiki Commons © Zero Gravity Corporation

WHAT HAPPENS ON A VOMIT COMET?



1 CLIMB

After lifting off the plane climbs steeply at a 45-degree angle, pinning passengers down with 1.8G.

2 WEIGHTLESS

As it reaches the top of the parabolic curve, at around 9,750 metres (32,000 feet), passengers experience weightlessness.

3 DROP

The aircraft drops down at 30 degrees to 7,300 metres (24,000 feet) before pulling back up into its next steep climb.

Whichever is true, Yaniec believes that it was anxiety that produced the most airsickness in zero-g aeronauts. However, as we evolved in a 1G environment, space adaptation syndrome (SAS) is a very real problem for those who boldly venture above the atmosphere. The first person to vomit in space was Russian cosmonaut Gherman Titov, who orbited Earth for a full day in 1961 aboard Vostok 2. He was about to eat one of his planned meals when nausea set in, and spent much of his flight feeling very ill, even after he managed eight hours' sleep. After 12 orbits of Earth he began to feel much better. History does not record the state of his capsule when it was retrieved after landing in Russia's Saratov Oblast region, but its subsequent reuse as a weight to test an experimental parachute system – a test that saw the spacecraft shattered into tiny pieces – perhaps tells us something.

Space adaptation syndrome can be thought of as motion sickness in reverse. While the two conditions affect a person's vestibular system – the bits of the inner ear that contribute to our balance and spatial orientation – motion sickness is a reaction to the difference between observed motion and felt motion, while SAS is a complete lack of felt motion, even though the eyes are insisting the body is moving. "Your body just isn't built to deal with zero gravity," says astronaut Steven Smith, veteran of four Space Shuttle flights and seven spacewalks. "There's no way of predicting how someone will handle it. Someone who gets car sick all the time can be fine in space – or the opposite. I'm fine in cars and on roller coasters, but space is a different matter."

Speaking of roller coasters, that's how MIT-trained engineer Emily Calandrelli describes her experience on the zero-g flight: "I think it's totally unique," she tells us. "The only thing that I can liken it to is if you are on a really big roller coaster where you get some air time. Like if the roller coaster goes over a hump really quickly and you lift off your seat and you get that butterfly feeling in your stomach. It's like that, just for longer."

Calandrelli has ridden the Comet three times, twice with NASA and once with the Zero Gravity Corporation. "The first time was as a student," she says. "I participated in the flight opportunities program that NASA had, so I was part of a class that was working on a science experiment that we were hoping to fly in microgravity, or weightlessness, and we designed an experiment and then submitted it to NASA."

The experiment was about laminar flows and the circular hydraulic jump. Watch water flow away down the sink and you'll see a circle of really smooth water bordered by bumpy water. This is a laminar flow, and it has different heat transfer properties than the water around it. It can be used to cool down electronics, and under different gravitational conditions the circle changes size, which is what Calandrelli's experiment measured.

"We turned on the faucet on the Vomit Comet to see how big that circle would be and just added to the data of what people already knew about

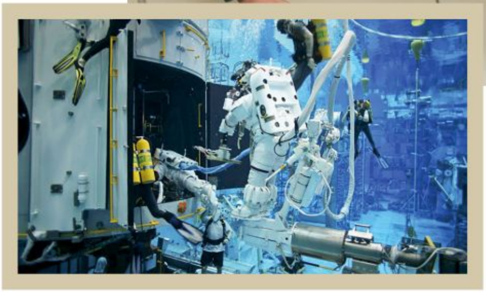
Left: Experiments aboard a French zero-g flight to study the effects of gravity on the distribution of brain flow in the vertebral and internal carotid arteries

WHY DO SOME PASSENGERS GET NAUSEOUS?

Your inner ears contain fluid-filled organs responsible for your sense of balance. When these organs are telling your brain that you're not moving – because the fluid is not reacting to gravity – but your eyes are telling it you are, then a feeling of nausea is the result.

Spinning volunteers in centrifuges for a few hours has shown that upon leaving the chair, about half the subjects suffered similar effects to space adaptation syndrome. This means it's not weightlessness itself, but the adaptation of the body to different gravitational conditions that leads to nausea.

Right: Scientist and TV host Emily Calandrelli on board a zero-g flight



© NASA

Above: Other methods of training astronauts include huge water tanks, where they achieve neutral buoyancy

fluid dynamics. We tried to understand how water worked in space and how water would work in a weightless environment," she says.

And despite being ostensibly 'work', it was an enjoyable experience. "I always tell people it's one of the coolest human experiences I've ever felt," she says. "It quite literally feels like you're flying, so it's just so joyful. I think my cheeks were hurting after 45 minutes on the flight because I was just smiling so much the whole time.

"There are a number of things happening at once," she continues. "You're experiencing something that your body has never experienced before, and you are just very excited about what's going on. But you're also a little bit disoriented, because if the plane is moving up and down and up and down you're feeling weightless and then heavy and weightless and then heavy. It's very chaotic and your body is moving all around. You can't just sit down in your chair and focus on your experiment and pull this lever and press that button. You have to find a way to hold on to something, to make sure your body doesn't fly away from your experiment, so that you can actually do your experiment."

And as for the idea that it's anxiety that makes people nauseous on a zero-g flight, Calandrelli describes it as a mixture of nervousness and excitement: "There are some nerves knowing you're going to be in a plane that's going to dive towards the ground. That is not the direction the planes are supposed to be flying, and so I was certainly nervous about that aspect of it, but I think after the first one, once you start doing the parabolas and everybody's having fun and it's just very exciting, then those fears just fly away.

"When you get back on the ground you feel great because now you've got the ground under your feet, but you're also exhausted. Like any experience where there's a lot of anxiety and excitement and nervousness that builds up, your body just runs through all that adrenaline. Once you come back down you're like, I need a nap."

Although NASA has run the flights since the early days of space exploration, in 2004 a private company, the Zero Gravity Corporation, began offering the service too, and has taken over the astronaut-training flights since 2008. Founded by a former astronaut, a NASA engineer and an entrepreneur, in 2006 it became the first private company to be granted permission to use the Kennedy Space Center's Shuttle Landing Facility on Merritt Island, Florida.

In 2007 it began flights for tourists from Las Vegas, at several thousand dollars per passenger for a 90-minute flight. You can even get married in zero gravity, and celebrities such as Buzz Aldrin, Steven Hawking and presenters from TV channels such as Discovery, National Geographic and the BBC have all risked the company's Boeing 727-227F Advanced, known colloquially as G-Force One.

Hollywood has also wanted to get in on the action, using the parabolic flights to film sequences in movies such as Apollo 13. The American space program isn't the only one in the world, and there are similar training flights operated on the other side of the Atlantic. The European Space Agency and French National Centre for Space Studies (CNES) have been running parabolic flights since 1984, currently using an Airbus A310 based at Bordeaux-Mérignac airport in France and operated by Novespace. From Russia you can take commercial flights aboard an Ilyushin Il-76.

The need for astronaut training can only increase as NASA gears up to send crewed missions to the Moon and Mars and space tourism becomes a very real possibility. As flights increase, prices will fall, and a brief burst of weightlessness aboard a parabolic flight might become an achievable dream for all. Just don't go without a sick bag.

Ian Evenden
Space science writer
Ian has been writing about the universe for over ten years, focusing on cosmology and space exploration. He's also a keen astrophotographer.

ALL ABOUT THE VOMIT COMET

How does this method of training work?

Do all astronauts go through these training flights?
Yes. Everyone from the Mercury and Apollo missions to Space Shuttle and ISS crews have endured parabolic flights.

Do you take anti-sickness medication?
If you're not an astronaut, yes. You take some pills about an hour before takeoff.

Is the inside of the plane padded?
Yes. You'll always have a soft landing wherever you get thrown.

Are there seats on the plane?
Yes. You take off and land like on a normal flight, but get out of your seats for the weightless experience.

How long does a flight take?
Commercial flights last about two hours. For experiments or astronaut training, they're longer.

COULD LIFE EXIST AROUND BLACK HOLES?

They warp time and space, but could they also nurture life?

Reported by Nigel Watson

TAP HERE TO PLAY

© Nicholas Forder

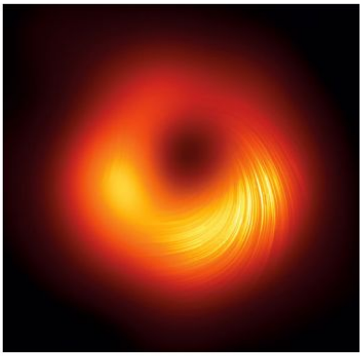
From the coldest to the hottest regions, life on Earth has filled every conceivable ecological niche. It's very likely life has evolved elsewhere, though despite our best efforts we haven't seen any signs of it yet. What is truly amazing is that scientists have speculated that life could exist on planets in the neighbourhood of black holes.

Black holes are the most extreme and awe-inspiring objects in the universe. At the centre of virtually every galaxy, including our own Milky Way, resides a menacing black hole that greedily consumes everything that falls into it - from vast dust clouds and planets to whole solar systems.

In the early evolution of galaxy formation, stellar material spinning around black holes formed flattened accretion discs billions of times the mass of our Sun, and great jets of gas fired out from them. These jets are like powerful beacons, 1,000 times brighter than our Milky Way, and are known as quasars. Much of the gas that fuelled quasars has run out in mature galaxies, but quasars can still be observed in very distant young galaxies.

The black hole itself is formed when a massive star has exhausted all its hydrogen and helium gases, causing it to violently explode and triggering its inner core to collapse in on itself. The outermost region of the black hole is the event horizon, and beyond that point the escape velocity to get out of the hole's gravitational pull is greater than the speed of light. Therefore nothing can escape this point of infinite density, known as the singularity.

If you do fall into a black hole it is a gruesome experience, as the intense gravitational field of the singularity will pull you into a long, thin strand. This process is rather aptly called spaghettification. Any object can be spaghettified, including entire stars.



© NASA

WHAT WOULD THE PLANETS BE LIKE?

The dust particles orbiting black holes could form rocky 'blanets' ten times larger than Earth, or create gas giants. Such planets are more likely around cooler and dimmer supermassive black holes, where essential planet-building ice-covered dust particles might exist.

Such blanets, or planets captured by a black hole's gravity, would be orbiting at least ten light years from the black hole, otherwise they would be in danger of being sucked into it, or its gravitational forces might strip away their planetary atmosphere. They would also be subjected to high levels of ultraviolet light and X-ray radiation.

The chance of a life-supporting black hole planet seems impossible, but scientists are never one to shirk a challenge. A big boost to such speculation was the fictional Miller's planet in Christopher Nolan's 2014 film *Interstellar*. This was mainly because it used advice from theoretical physicist Dr Kip Thorne about the properties of wormholes and black holes. Although the science was praised, it was thought a planet so close to a black hole, with the time-dilation effects shown, would easily be blasted with lethal radiation and would be in serious danger of being drawn into the hole.

A group of astrophysicists led by Pavel Bakala of the Silesian University in Opava decided to take another look at this problem. Considering the thermodynamics of the situation, they postulated that the black hole would act as a heat sink for unusable waste heat - equivalent to the cold of space surrounding Earth. The usable energy would come from the cosmic microwave background (CMB) rather than a star like our Sun.

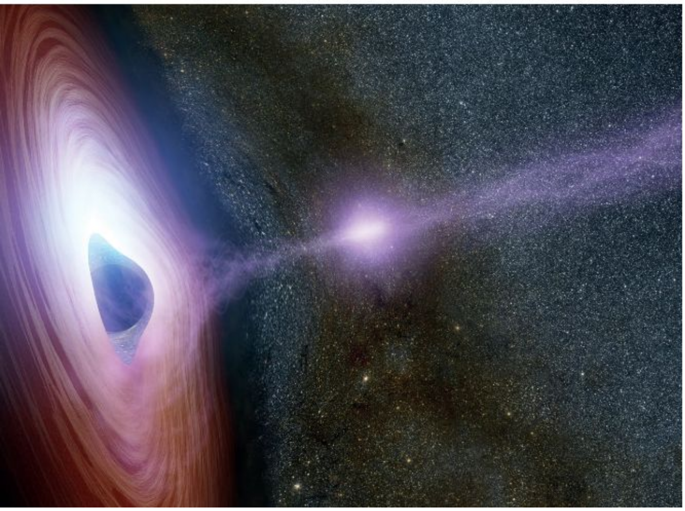
The CMB as a source of energy does not sound very promising, as it is relatively weak, but a supermassive black hole could compress and funnel it into optical wavelengths. Its narrow beam of light would look like a bright star near the shadow of the black hole to an observer on a nearby planet.

Four years after putting forward that idea, the team refined it to account for the weakness of the CMB. This could be catered for if the planet is in an orbit close to the black hole, the danger of course being that it might be drawn into its singularity. To avoid this they calculated that a planet would be able to be in a close, stable orbit with strong enough CMB light if the black hole spun at a 100 millionth less than the speed of light.

The black hole in our Milky Way, although having a mass around 4 million times larger than the Sun, would be too small, and would rip apart any nearby planet. For a planet to evade that fate it would have to orbit a supermassive black hole that only rips up planets when they go beyond its event horizon. Such black holes would have to have a mass of at least 163 million times that of our Sun.

Another consideration is that the black hole would need to be in a fairly old galaxy, with plenty of empty space around it. Otherwise any matter in the area that is sucked into the black hole would blast out deadly radiation as it spirals to certain doom inside the singularity.

Instead of the weak CMB, the energy from the accretion disc surrounding a black hole could be an alternative. Jeremy Schnittman, a research astrophysicist at NASA's Goddard Space Flight Center, who was also inspired by *Interstellar*, has considered that the bright, hot gas from the



© NASA

Above: A polarised image of the magnetic fields spinning around a black hole, released in March 2021, using data from radio telescopes around the world

Left: An artist's concept of a corona flare of energetic particles shooting out from a supermassive black hole

HOW CAN LIFE EXIST AROUND A BLACK HOLE?

Could lifeforms survive in such an inhospitable environment?

1 PLENTY OF SPACE FOR PLANETS

The amount of dust and material surrounding a supermassive black hole is enough to help create at least 10,000 planets.

2 ACCRETION DISC WOULD ACT LIKE A SUN

Instead of a life-giving Sun, the energy from an accretion disc would provide planets, at the right distance, a Sun-like presence.

3 THICK ATMOSPHERE

UV and X-ray radiation from an accretion disc could wipe out life on a planet unless it's protected by a thick, cloudy atmosphere, or if one face of the planet is always facing away.

4 RING OF STARS

As an alternative to an energy-providing accretion disc, a ring of stars between a black hole and orbiting planets could provide solar energy.

5 COSMIC RADIATION AS A SOURCE OF ENERGY

Gravity of a black hole spinning at the speed of light could focus energy to a nearby planet, providing a possible alternative.

6 BRIGHT AND INTENSE SKY

The sky at night on a black-hole planet would be 100,000 times brighter than on Earth, and the stars would only be visible in a small zone of the night sky.

7 SPACE-TIME CONTINUUM

Black holes warp time as well as space, so a planet's time could be as much as 1,000 times slower than that experienced on Earth.

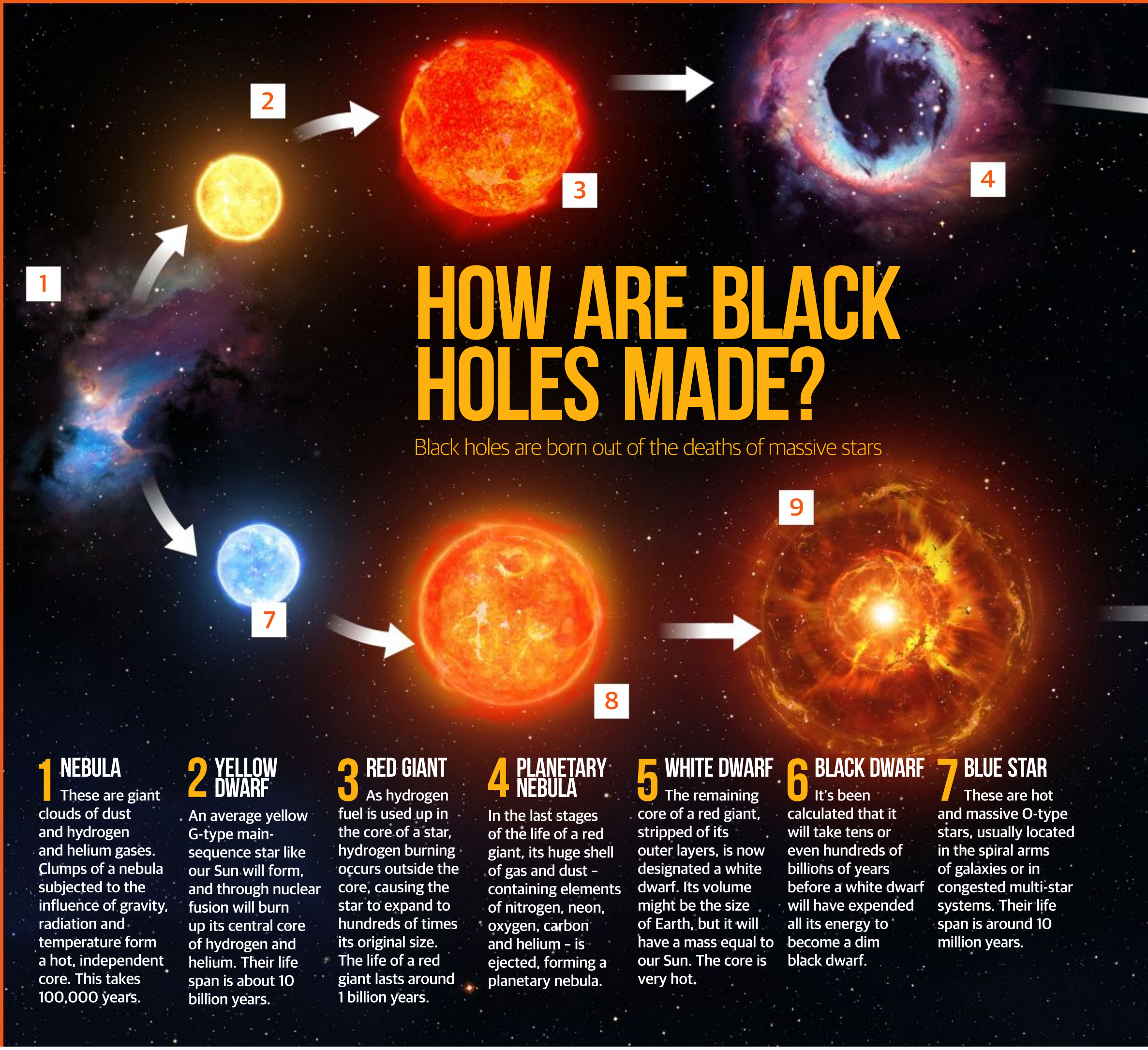
8 GRAVITY'S INFLUENCE

Earth tilts a few degrees over a 41,000-year cycle. A blanet's obliquity would vary tens of degrees in 400 years. Such instability could make it less suitable for life.

© Getty

HOW ARE BLACK HOLES MADE?

Black holes are born out of the deaths of massive stars



© Tobias Roetsch

1 NEBULA These are giant clouds of dust and hydrogen and helium gases. Clumps of a nebula subjected to the influence of gravity, radiation and temperature form a hot, independent core. This takes 100,000 years.

2 YELLOW DWARF An average yellow G-type main-sequence star like our Sun will form, and through nuclear fusion will burn up its central core of hydrogen and helium. Their life span is about 10 billion years.

3 RED GIANT As hydrogen fuel is used up in the core of a star, hydrogen burning occurs outside the core, causing the star to expand to hundreds of times its original size. The life of a red giant lasts around 1 billion years.

4 PLANETARY NEBULA In the last stages of the life of a red giant, its huge shell of gas and dust – containing elements of nitrogen, neon, oxygen, carbon and helium – is ejected, forming a planetary nebula.

5 WHITE DWARF The remaining core of a red giant, stripped of its outer layers, is now designated a white dwarf. Its volume might be the size of Earth, but it will have a mass equal to our Sun. The core is very hot.

6 BLACK DWARF It's been calculated that it will take tens or even hundreds of billions of years before a white dwarf will have expended all its energy to become a dim black dwarf.

7 BLUE STAR These are hot and massive O-type stars, usually located in the spiral arms of galaxies or in congested multi-star systems. Their life span is around 10 million years.

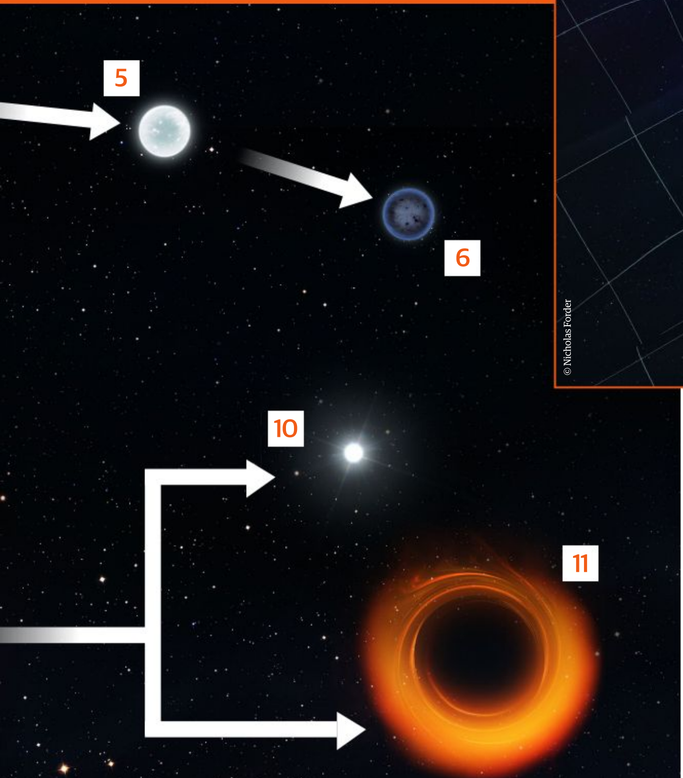
accretion disc could provide the energy and light to sustain life forms. That's the good news, but he also believes that the nearby influence of a black hole would amplify and intensify ultraviolet rays to such an extent that it would wipe out any life.

Keiichi Wada of Kagoshima University, Japan, and his team note that more distant and relatively safe zones around supermassive black holes could be inhabited by planets and stars captured by its powerful gravitational forces. From there they speculate that dust particles and gasses in the same zone could be pulled together to create new planets that they have termed 'blanets', short for black hole planets.

There are several factors that condition the formation of a blanet. One is that the dust and rocks could smash themselves apart rather than clump together. To help with clumping, ice-covered dust particles are required. Given the right conditions, they calculate that at a distance of 13 light years from a black hole with a mass 1 million times that of our Sun, blanets could grow from 20 to 3,000 times the mass of Earth over a period of about 80 million years.

Much depends on the mass of the black hole and the distance from it. For a black hole with a mass 10 million times our Sun's, blanets could become as massive as gas giants or stars. The team certainly agrees that blanets would be very different from the type of planets formed in solar systems like our own. It might also take equally different types of life to evolve in what we would regard as a very inhospitable environment.

Sean N. Raymond, at the Observatory of Bordeaux in France, notes: "What does life need? If we're shooting for Earth-like life, then it would



8 RED SUPERGIANT

As the hydrogen and helium at the core are burnt off in large stars – those 10 to 40 times the size of our Sun – outer layers expand at a rapid rate. They have a life span of a few million years.

9 SUPERNOVA

This is the gigantic explosion caused when a supergiant runs out of fuel. Within a few seconds the mass is crushed towards its core, resulting in shock waves that trigger the explosion of its outer layers.

10 NEUTRON STAR

A neutron star is incredibly dense – gravity is an astonishing 200 billion times that of Earth's. One tablespoon of a neutron star is equivalent to the weight of Everest.

11 BLACK HOLE

The explosive power of a supernova can produce a black hole at its core. Its gravity is so powerful that even light cannot escape it, and it distorts the space-time continuum with its immense mass.

© Nicholas Forder

Above: The Laser Interferometer Space Antenna will launch in 2034, able to detect tiny ripples caused by black holes colliding, called gravitational waves

Below: Artist's impression of a supermassive black hole 800 million times the mass of the Sun, with quasar jets blasting away from it

© NASA

> "PLANETS HAVE BEEN FOUND AROUND NEUTRON STARS, SO IT'S REASONABLE TO EXPECT THEM TO SURVIVE" SEAN RAYMOND

need a rocky planet, liquid water and the right amount of energy. Too much energy would strip a planet's atmosphere and surface water; too little would leave the surface frozen over.

"Planets have actually been found around neutron stars, so it's reasonable to expect them to survive around solar-mass black holes. Could such planets form with water? That's a big 'who knows?' I think it's plausible to imagine that water could end up on a planet around a black hole, simply because water is so abundant in the universe. But the exact mechanisms at play have not been studied in great detail," Raymond explains.

"Supermassive black holes are known to have accretion discs. These are extremely luminous, which is really not a problem for life – the 'habitable zone' would simply be moved farther from the black hole. What may be problematic is that the radiation from black hole accretion discs can be very 'hard', with a lot of energy being emitted at very high-energy wavelengths. High-energy radiation can strip planetary atmospheres and water – not great for life.

"If we take the worst case scenario of a planet completely bathed in high-energy radiation, is it hopeless for life? Probably, but you can easily imagine localised habitable regions," he continues. "For instance, if the planet is tidally locked to the black hole, then the dark side of the planet may be more hospitable to life. Even without tidal locking, subsurface water could presumably exist for long timescales, as it might still exist on Mars today. Or volcanic hot spots could provide a trickle of atmosphere and water…"

As a thought experiment, Raymond considers that 550 Earth-sized planets could orbit in the habitable zone of a supermassive black hole. In comparison, only six Earth-sized planets would be able to stay in stable orbits within the habitable zone of our Sun.

The hypothetical black hole would have a million times more mass than the Sun, and its gravity would pull at the planets, moving them out of the habitable zone. To keep them in the habitable zone in stable, concentric orbits, a ring of nine Sun-like stars would need to be between the black hole and the planets. The stars would take three hours to orbit the black hole, and the planets would orbit it in a range of 1.6 to 4.6 days.

Abraham 'Avi' Loeb of Harvard University has also stretched his imagination by considering the numerous benefits of living near a supermassive black hole. This includes using the accretion disc as the ultimate garbage-disposal system - one that would produce radiation from the waste to provide a source of energy.

The immensely powerful jets of energy sent out by the black hole could power a spacecraft with a lightsail close to the speed of light. For the more adventurous, you could ride on a planet at the speed of light powered by the gravitational forces generated when two black holes merge together.

In his essay *Shooting Stars at the Speed of Light*, Loeb notes: "All in all galactic nuclei offer launching sites for the fastest habitable platforms that nature offers for free. It would not be surprising if advanced technological civilisations choose to migrate towards galactic centres for the same reason that astronauts and spectators flock to Cape Canaveral during rocket launches. With that perspective in mind, the Search for Extraterrestrial Intelligence (SETI) should check for radio signals coming from riders of hypervelocity stars."

Given all the dangers a black hole presents, it's difficult to know how a habitable planet could exist against all these odds. Any life form would have to deal with the high levels of radiation, too much or too few suitable sources of light and energy, the erratic bursts of radiation from the black hole's accretion disc, space debris, an unstable and unsustainable orbit and the effects of time dilation.

Perhaps only primitive life might evolve on such planets, or fast evolving and very adaptable intelligent species might exist on them. Raymond offers some hope: "I would expect life to be harsher on planets around black holes, but I think that seeing them as necessarily barren, inhospitable worlds is a failure of imagination."

© NASA

Left: Rendition of the accretion discs of two supermassive black holes interacting

Below: Artistic view of findings that indicate black holes can blast out vast amounts of matter in all directions

Nigel Watson
Space science writer
Nigel has written extensively about science and technology, in particular about extraterrestrial contact. He is the author of four books on alien life.

© NASA

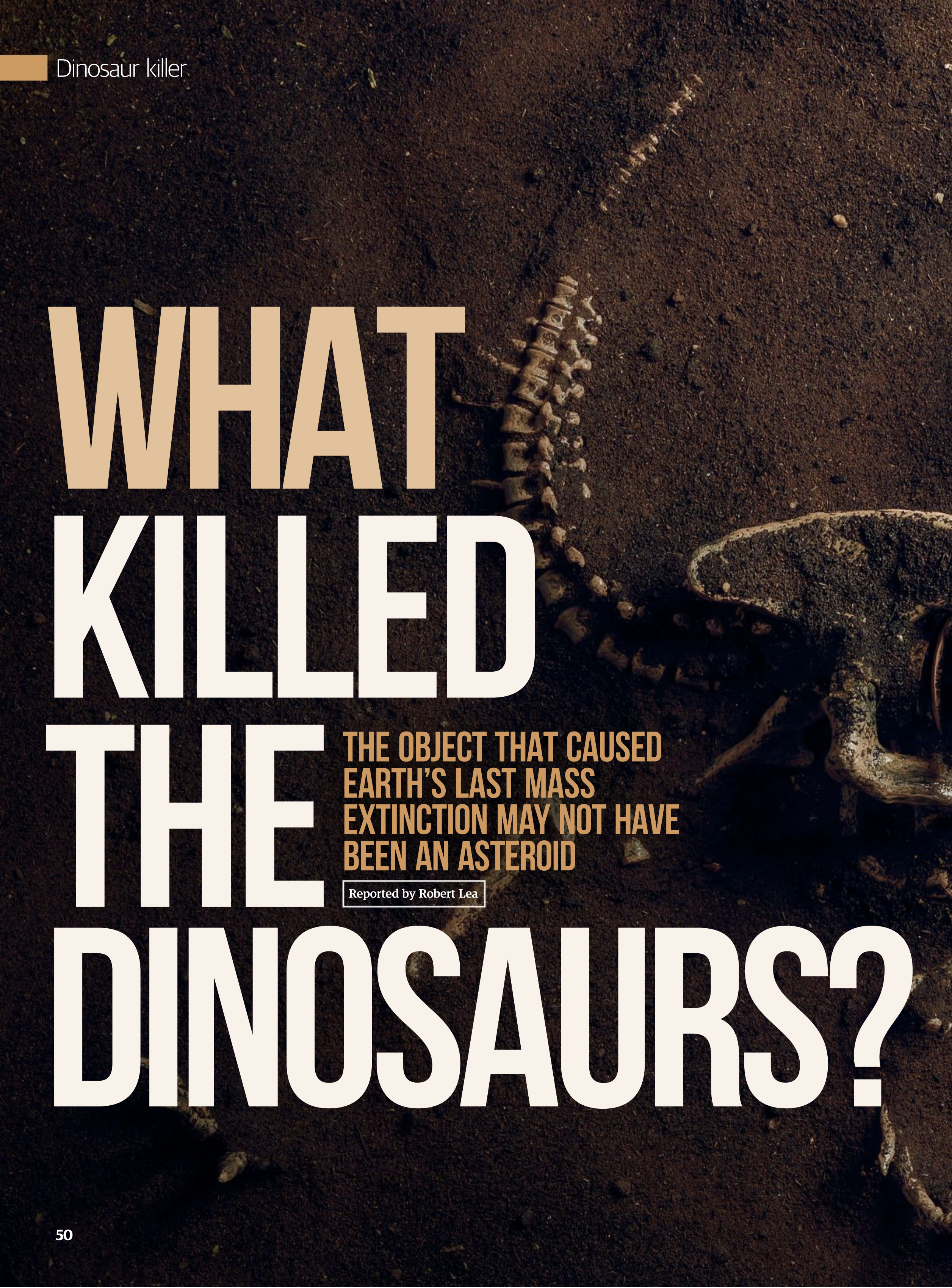
Don't miss out on your favourite TV magazine!

TV Times
Britain's best-loved TV magazine
Our Strictly stories
Maisie, Caroline and Ranvir their all and having
NEW
His Dark Materials
The dangers that await as the drama returns...
Britain's Great Escape
'I did yoga with alpacas and fell in love with a horse'
BEST FOR SKY & VIRGIN
MORE CHANNELS THAN ANY OTHER TV MAG!
TV & Satellite week
PLUS 5-PAGE WEEKLY GUIDE
NETFLIX
prime
BBC iPlayer
Disney+
and more...
NEW STRICTLY
It's the launch show!
NEW
ROADKILL
Hugh Laurie plays a power-hungry politician with secrets to hide
THRILLER STARTS SUNDAY ON BBC1 HD
NEW DRAMA
NEW DRAMA
LIVE FOOTBALL

On sale every Tuesday

Also available as a print or digital subscription from

www.magazinesdirect.com



WHAT KILLED THE DINOSAURS?

THE OBJECT THAT CAUSED EARTH'S LAST MASS EXTINCTION MAY NOT HAVE BEEN AN ASTEROID

Reported by Robert Lea

© Getty

> "LONG-PERIOD COMETS MAY ALSO POSE LONG-TERM HAZARDS TO HUMANS AND EARTH'S BIOSPHERE" MANASVI LINGAM

Researchers are fairly certain that the object known as the Chicxulub impactor ended the dinosaurs' reign over Earth 66 million years ago when it crashed into the planet. The huge impact released energy equivalent to the detonation of 21 to 921 billion nuclear bombs, so it wasn't just the dinosaurs that bore the brunt of the devastation. The impact sparked what geologists call the Cretaceous-Tertiary (K-T) extinction, an event that saw the elimination of around 80 per cent of the planet's animal species.

Evidence of this violent impact is found in Earth's geological record, most strikingly in the shape of a 150-kilometre (93-mile) wide and 19.3-kilometre (12-mile) deep crater carved into our planet at the Yucatán Peninsula in Mexico. Yet despite the wealth of information about this collision between Earth and the Chicxulub impactor, there are still mysteries surrounding the object itself and the processes that caused it.

One of the most pressing puzzles that surrounds the Chicxulub impactor is just where this 80-kilometre (50-mile) wide 'planet killer' came from, and the details of its journey to Earth. The source of this mystery is the fact the impact rate for the main suspects - both main-belt asteroids and long-period comets - are just too low to account for the Chicxulub event.

Unlocking the mysteries of the Chicxulub impactor is the goal of Abraham 'Avi' Loeb of the Harvard-Smithsonian Center for Astrophysics and Amir Siraj, an astrophysicist at Harvard University. Their work implies that the solution to this puzzle may reveal that the asteroid that killed the dinosaurs wasn't an asteroid at all - rather it could have been a piece of 'shrapnel' originating from a long-period comet that was dragged from its position at the edge of the Solar System and violently ripped apart. The research could also show that the threat to Earth from objects falling from space is more considerably significant than currently estimated.

"In the early 1980s, Luis Alvarez, a Nobel laureate in physics, and his son, geologist Walter Alvarez, made the breakthrough discovery that the Chicxulub impactor and the global extinction that occurred around the same time were connected," Siraj tells **All About Space**. "This sparked intense scientific interest in understanding the origin of the impactor. But the more that theorists looked at the puzzle, the stranger it became."

Loeb and Siraj are the authors of a paper published in the journal *Scientific Reports* documenting one possible origin for the Chicxulub impactor, its journey to our planet and how this was influenced by the Solar System's other bodies. The duo's model confirms that the object could have broken away from a much larger cometary body. "The model tries to answer this question by identifying a special population of comets that can produce the necessary size and rate of impactors to explain Chicxulub in a way that is consistent with all of the data that we have," continues Siraj.

Loeb and Siraj calculated the expected impact rate of an object with the size of the Chicxulub impactor by considering the incidence rate of long-period comets from the Oort Cloud - a shell of icy debris called planetesimals lurking at the very outskirts of the Solar System, which Loeb colourfully describes as the bricks left over from the construction project of the planets.

"We showed that a fraction of these long-period comets from the outskirts of the Solar system can be broken into pieces when they pass near the Sun," says Loeb. "Their break-up produces a collection of small fragments that cross the orbit of Earth." The pair found that these fragments increase the rate of giant rocks raining down on the surface of Earth from space significantly. This has the effect of making the rate of incidence consistent with the age of the Chicxulub crater.

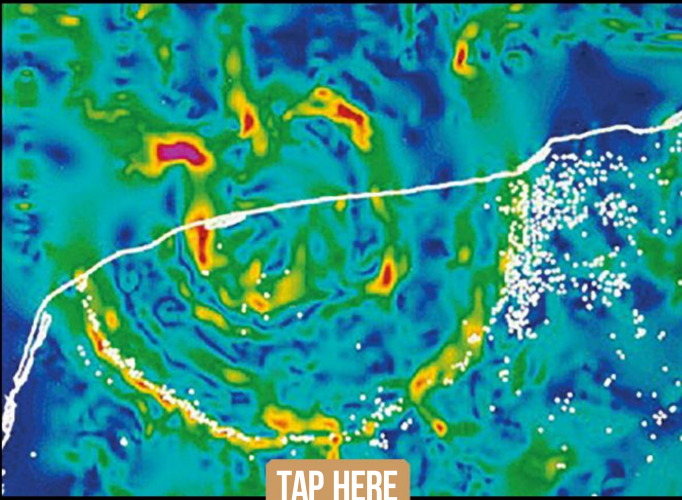
There is also other evidence that suggests the origin of the Chicxulub impactor was a piece of a larger body which broke away before striking Earth. Some of this comes from two similar craters - one smaller, and another considerably larger.

"The cometary origin of the Chicxulub impactor also explains the composition of the largest impact crater on Earth, Vredefort, located in South Africa, which at 305 kilometres (190 miles) across is twice the size of the Chicxulub crater," Loeb

Right: A gravity map of the Chicxulub crater reveals concentric rings marking the impact site in stunning detail

Below: Whether it was an asteroid or comet fragment, the impactor was deadly

Below right: The shock wave from the impact would have obliterated everything in its path


© Public Domain

© Alamy

TAP HERE TO PLAY

© Getty

THE DINOSAURS' DEMISE

The Chicxulub impactor's collision with Earth triggered an immediate and catastrophic sequence of events

GROUND ZERO

The Chicxulub impactor touched down on the surface of Earth, releasing the equivalent energy of billions of nuclear weapons simultaneously detonating.

0 SECONDS

THE WINDS OF CHANGE

The impact triggered a deadly airblast of 1,000 kilometre (620 mile) per hour winds that stripped the land bare of life for a radius of up to 1,800 kilometres (1,118 miles).

SECONDS TO MINUTES AFTER THE BLAST

WHAT GOES UP...

The impact created shock waves, generating an earthquake and shedding soils and vegetation, as well as throwing debris high into Earth's atmosphere.

...MUST COME DOWN

The ejected material that was thrown beyond Earth's atmosphere started to fall back, raining down on the Gulf of Mexico and the Caribbean.

40 MINUTES AFTER THE BLAST

DEATH FROM ABOVE

The effect of the ejecta re-entering the atmosphere caused an intense burst of infrared radiation, cooking any organisms exposed to it.

MINUTES TO HOURS AFTER THE BLAST

AND BELOW

Because the impactor touched down at sea it triggered a titanic tsunami. These waves devastated coastal ecosystems and destroyed life on the seafloor.

MINUTES TO TEN HOURS AFTER THE BLAST

> "BUT THE MORE THAT THEORISTS LOOKED AT THE PUZZLE, THE STRANGER IT BECAME"
>
> AMIR SIRAJ

© Getty

explains. The researcher says that the shrapnel model implies that fragments smaller than the Chicxulub impactor, but with a similar make-up, should strike Earth every million or so years.

Loeb adds that this could account for the existence of the Zhamanshin crater – the remains of a meteorite crash in Kazakhstan which is around 14.5 kilometres (nine miles) in diameter and formed within the last million years. It's ten times smaller than the Chicxulub crater, yet shows signs of an object that has a similar composition.

The composition of the objects at the centre of the three impact events is likely to be a source of further study. The paper assumes that 20 to 50 per cent of all long-period comets have a carbonaceous chondritic composition, consisting mainly of water, silicates, oxides and sulphides with the minerals olivine and serpentine, for which there isn't currently a great deal of empirical evidence.

Fortunately, the duo's findings are consistent with other investigations, including some that concern the origin of the Solar System itself. "Our hypothesis is consistent with Solar System formation theories in which there exist well-separated reservoirs of carbonaceous chondritic material beyond the orbit of Jupiter in the solar protoplanetary disc," Siraj says. "Future observations of the chemical compositions of comets will allow for our hypothesis to be tested."

Siraj reflects on his surprise that the model he and Loeb developed connected to these other craters: "The fact our hypothesis explains the largest confirmed crater in Earth's history, Vredefort – the only one larger than Chicxulub – was a surprise to me," the astrophysicist says. "As was the fact that it also explains the largest recently formed confirmed crater, Zhamanshin."

Siraj also describes the process that could have fractured the parent body of the Chicxulub impactor, connecting it with the phenomenon that allows us to study these objects. "When the orbits of long-period comets, originating from the Oort Cloud, bring them through the inner Solar System, the Sun heats up their volatile ices and allows them to develop these stunning cometary tails, which help astronomers locate and study them," Siraj says. "Since they spend most of their time far away from the Sun, comets are particularly sensitive to gravitational interactions with the Sun and the planets," he continues. "This is much like the way a great musician performing with an orchestra becomes attuned to the musical gestures coming from both the conductor and the individual sections."

The pair's paper describes what happened when the parent body of the Chicxulub impactor flew too close to the Sun and experienced a much more powerful gravitational influence on one side than the other, giving rise to a tidal force within the body. "This force was so strong that it ripped the comet apart, producing a field of cometary shrapnel," says Siraj, pointing out that our knowledge of this process is still somewhat vague. "The tidal disruption of comets is not yet fully understood, including the number of fragments that are produced in such events."

The Sun wasn't the only Solar System body that played a role in the disastrous meeting between the Chicxulub impactor and Earth. The researchers point out that its second and third-largest bodies were also significant in the orchestration of this calamitous event by pulling long-range comets from the Oort Cloud towards their demise. "Like a pinball machine, the Jupiter-Sun system shapes the orbits of comets that enter the inner region of the Solar System, pushing a fraction of all cometary orbits very close to the Sun," Siraj explains. "During these passages close to the Sun, large comets are

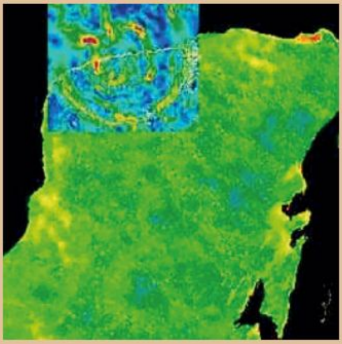
© NASA

Left: An artist's illustration of the impact of a body similar to the Chicxulub impactor

THE CHICXULUB CRATER

The collision with the Chicxulub impactor left a scar on Earth

The crater is buried beneath the Yucatán Peninsula in Mexico. It's the second-largest impact crater on Earth, discovered in 1978 by Glen Penfield and Antonio Camargo as part of an airborne magnetic study. They cross-referenced this with gravimetric data collected in the 1940s, confirming the presence of the crater. Their evidence of the crater was presented in 1981, a year after father and son team Luis and Walter Alvarez, unaware of the crater's discovery, suggested that a massive body from space had struck Earth 66 million years ago.



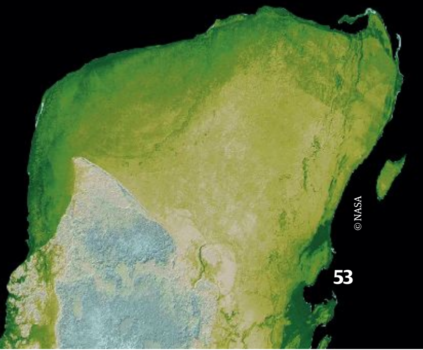
©NASA

CHICXULUB IMPACTOR

Researchers have been able to estimate some important numbers surrounding the Chicxulub impactor

The Chicxulub impactor is estimated to have had a diameter of between 10 and 17 kilometres (6.2 and 10.5 miles). Recent simulations show that it was likely to have hit the Earth at an angle of between 45 and 60 degrees, with a speed ranging from 12 to 20 kilometres (7.4 to 12.4 miles) per second.

This massive impact released an estimated 5.8×10^{25} joules of energy, equivalent to up to 921 billion A-bombs. These are just estimates, and there is still much to discover about this object that radically shaped our world.



© NASA

A LASTING IMPACT

The effects of the Chicxulub impact were long-lasting and global

A world on fire

1 Perhaps the most widespread effect of the impact was the rise in temperatures. The kinetic energy of the ejected debris was around 20 million megatonnes. This was converted to heat as the debris fell.

Cruel seas

2 The immediate tsunami resulted in a backwash that caused further, albeit smaller, tsunamis. Earthquakes and landslides around the globe triggered other tsunamis as far away as Argentina.

Prehistoric napalm

3 Debris from the impact continued to fall, with fragments lighting wildfires, spelling doom for any animals caught out in the open. This was disastrous for terrestrial species.

Darkness falls

4 The diversity of life had already been severely truncated by the impact and its events. But perhaps more deadly was the effect of debris that did not immediately fall down…

Eternal winter

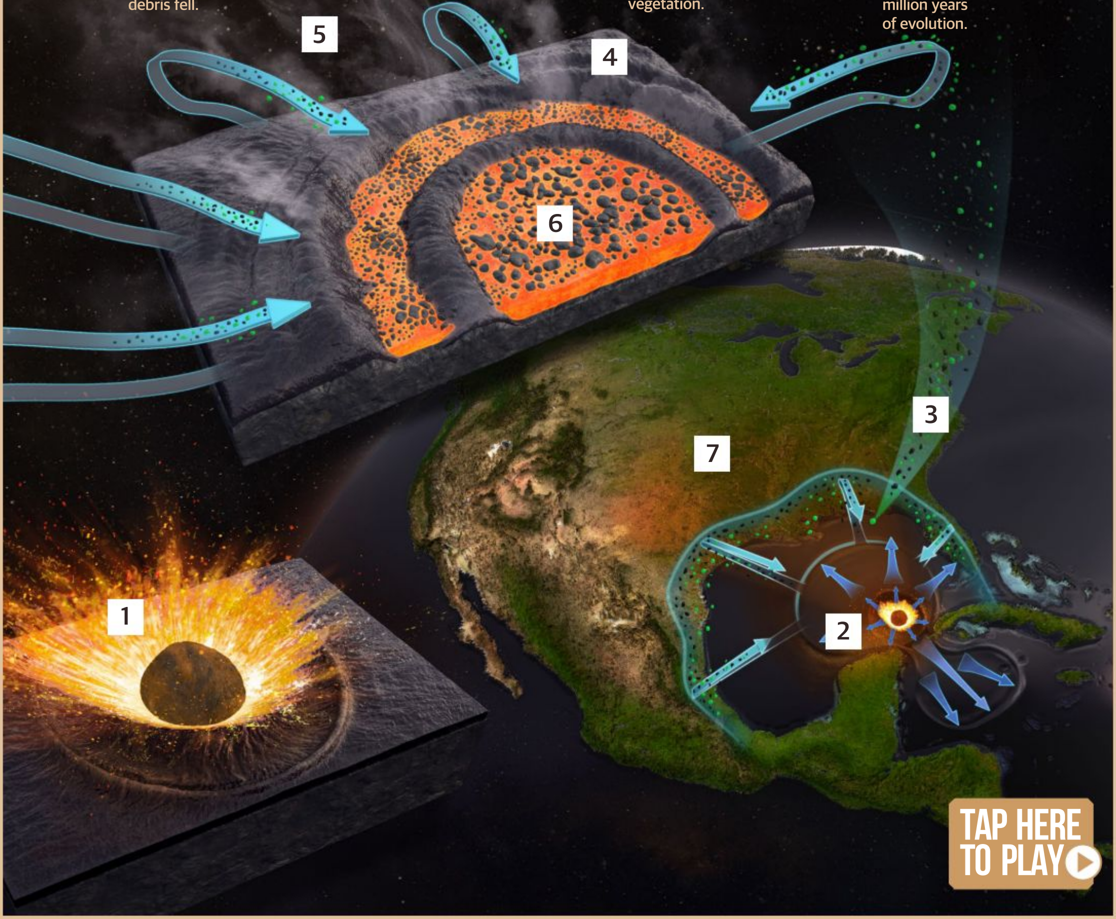
5 Dust and soot from the impact remained in the atmosphere, blocking the Sun for at least a year. Species that survived the firestorm would fall to the cold or starvation as a result of diminished vegetation.

A barren Earth

6 Evolution had taken 180 million years to build the kingdom of the dinosaurs. The Chicxulub impactor and its short and long-term effects wiped all this out within years.

A new hope…

7 Around 25 per cent of Earth's species remained after the impact, consisting of scattered individuals. These lucky survivors would begin the world's repopulation, setting the scene for the next 66 million years of evolution.



© Nicholas Forder

© NASA/ESA

tidally disrupted, producing fields of cometary shrapnel."

Most of these Chicxulub-sized fragments miss Earth, but the chance that any one of them hits Earth in a given period of time is actually greater than the chance that a similarly sized asteroid or comet strikes. "In other words, the break-up of enormous comets by the Sun actually results in a higher rate of Chicxulub-sized impactors than the rate provided by impactors that were originally that size," Siraj adds.

As staggering in size as the crater left behind by the collision between Earth and the Chicxulub impactor is, the impact has left an even more startling legacy on our planet. The elimination of the dinosaurs allowed the rise of mammals, and in turn the evolution of humans. Were it not for the Chicxulub impactor and the mass extinction it sparked, we likely wouldn't even be here today. Just as such an event allowed the rise of humankind, scientists are painfully aware that a similar impact could potentially cause its fall.

"Knowing the source of the impactor can better inform us in our future predictions of the risks posed by large impactors," Manasvi Lingam of the Florida Institute of Technology, who helped review the study, tells us. "Most of the focus has been on asteroids, but this study suggests that long-period comets may also pose long-term hazards to humans and Earth's biosphere."

The fact that Loeb and Siraj's work suggests a higher incidence of impacts from large pieces of cometary shrapnel like the Chicxulub impactor should be a concern for scientists and governments across the globe. But it may not be time to start doomsday preparations just yet. Loeb suggests our species' investment in science could be its redemption.

"The human body is much smaller than that of a dinosaur, but the human brain is much more valuable for long-term survival," Loeb says. "It allows us to build telescopes that would warn us about incoming rocks and deflect them away from Earth." Loeb points to the upcoming Large Survey of Space and Time (LSST) to be conducted at the Vera C. Rubin observatory, due to begin monitoring the Chilean sky in 2023. Part of the LSST's mission is to better map objects in the immediate vicinity of Earth, projected to result in the identification of two-thirds of all rocks larger than a football field – a percentage the size of the Chicxulub impactor. "Our future is brighter than that of the helpless dinosaurs," Loeb concludes.

Robert Lea

Space science reporter

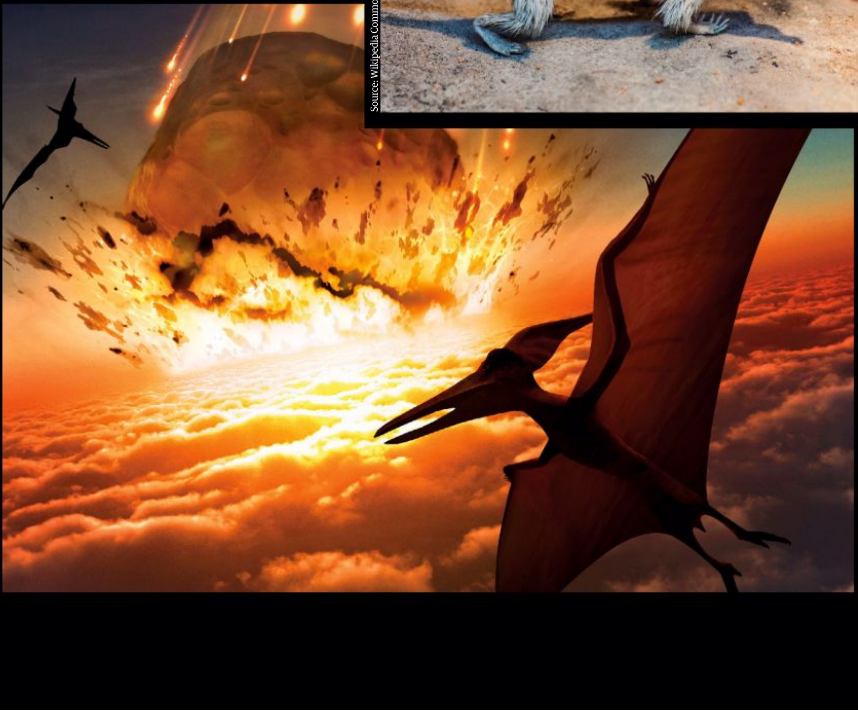
Rob is a science writer with a degree in physics and astronomy. He specialises in physics, astronomy, astrophysics and quantum physics.

Top: Jupiter and Saturn form a 'cosmic pinball machine' that drags objects into the inner Solar System

Below: Shrew-like mammals evolved from species like the *Megazostrodon* were well-equipped to survive the impact

Bottom: A massive airblast and ferocious winds wiped out aerial reptiles

Source: Wikipedia Commons © Theklan

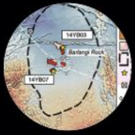

© Getty

EARTH'S RECORD-BREAKING IMPACT CRATERS

While the Chicxulub impactor is likely the most important object to strike Earth from space, it is by no means the only notable example

THE OLDEST: YARRABUBBA CRATER

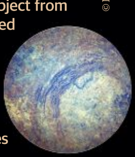
The oldest crater discovered resulted from a meteorite crash which occurred 2.23 billion years ago. The crater is located in Western Australia and was discovered in 2020.



Source: Wikipedia Commons © Timmons M. Erickson, Christopher L. Kirkland, Nicholas E. Timms, Aaron J. Cavosie & Thomas M. Davison

THE BIGGEST: VREDEFORT CRATER

The largest crater resulting from a collision with an object from space, which occurred 2 billion years ago. The crater is in the Free State province of South Africa and has a diameter of up to 300 kilometres (186 miles).


© NASA

MOST VISUALLY IMPRESSIVE: PINGUALUIT CRATER

This crater, found in northern Quebec, Canada, now contains Lake Pingualuk. Created by an impact millions of years ago, the near-black surface of the lake is a stunning contrast to the bone-white icy landscape.

© NASA

YOUNGEST: KAMIL CRATER

Objects from space are hitting Earth at a pretty constant rate, so it's difficult to pin down the youngest crater. This one found in Egypt in 2008 using Google Earth is roughly 45 metres (148 feet) wide and is believed to date back just 5,000 years.

© Public Domain

HOW DO ASTRONAUTS CLEAN A SPACE STATION?

Astronauts have to keep the space station clean to keep microbes under control

Reported by Tereza Pultarova

International Space Station astronauts don't have time to sleep in on Saturday mornings. They're far too busy sticking to their strict cleaning schedule. Saturday is their big 'cleaning day', when surfaces have to be sanitised and dust removed. On 30 April, European Space Agency (ESA) astronaut Thomas Pesquet, who arrived at the orbital outpost aboard Dragon Crew Endeavour on 24 April, shared insights into what a space station cleaning routine looks like.

The inhabitants of the International Space Station are kept as safe as possible from the ongoing COVID-19 pandemic: strict preflight quarantine and other safety measures are in place for crew members, as well as newly delivered equipment, Pesquet said.

However, keeping potentially harmful microorganisms in check is still an important part of safe living in space, and improper hygiene habits have no place on board the station. "We have to disinfect all the surfaces we touch every week," Pesquet said. "We also have a lot of measures on the space station that are similar to those you can find in hospitals or at airports that are designed to prevent the propagation of bacteria."

While microbe populations – like the microbiomes in our guts – are necessary for human health, the growth of harmful microorganisms in a closed environment such as the International Space Station, where air is constantly recycled, could create the risk of serious health problems. Therefore the space station currently hosts several experiments that test various antibacterial and antiviral materials designed to prevent the growth of microorganisms that come into contact with them, Pesquet mentioned. Several space agencies are studying advanced materials that could make future space travel safer. Such materials could do the same job on Earth, protecting door knobs, elevator buttons and other objects that humans frequently touch.

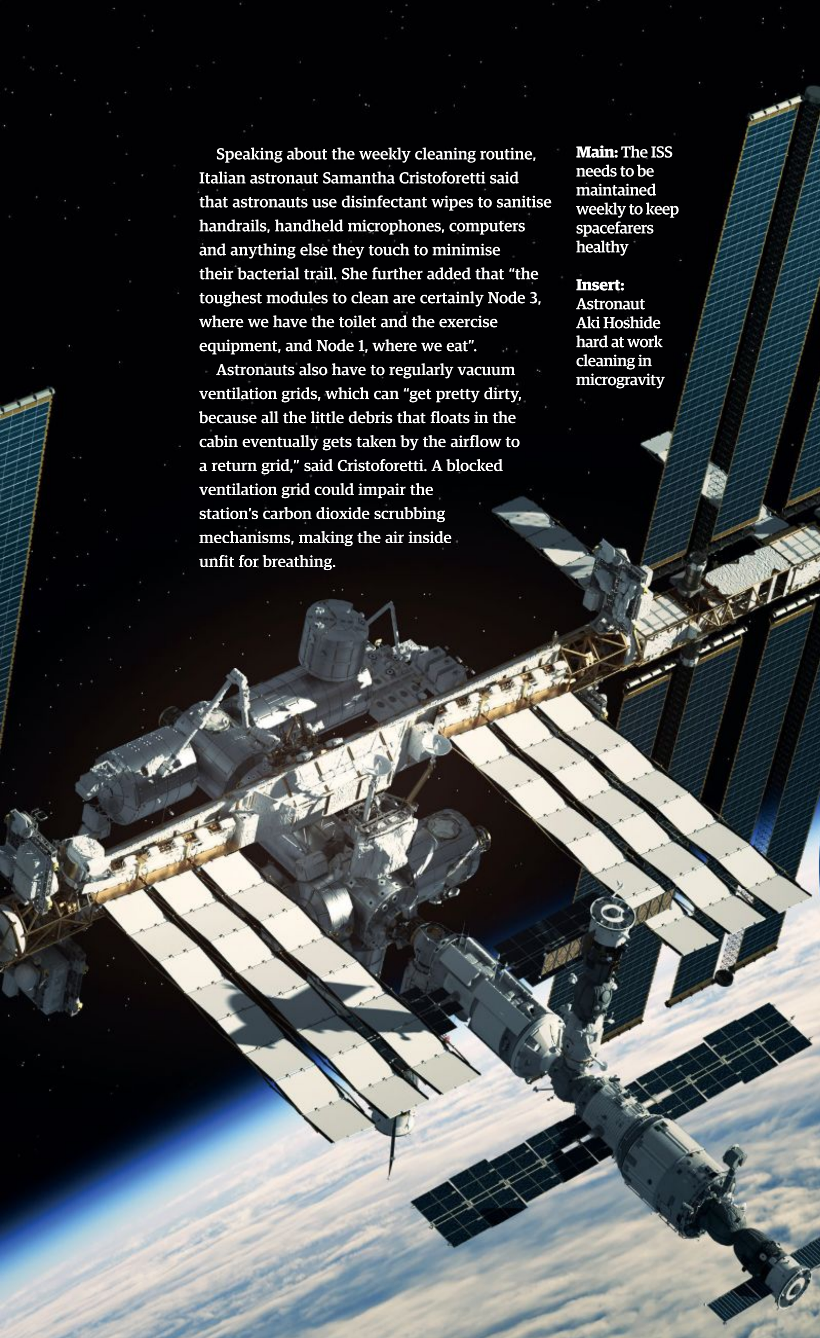
Earlier this year, a Boeing-led experiment began at the space station testing a new type of antimicrobial surface coating that could help to prevent the spread of microbes, including the SARS-CoV-2 virus, in aeroplanes. The experiment requires astronauts to regularly touch two sets of objects, including an aeroplane seat buckle, a piece of seat belt fabric and a tray table. Only one set of objects is treated with the coating. As the astronauts touch the objects, they transmit microbes that naturally occur on human skin. After the samples return to Earth, Boeing will analyse how effectively the coating stopped the spread of the microorganisms.

The ESA previously ran a similar set of experiments to test the ability of five types of surface materials to repel microbes. The experiment, called MatISS (Microbial Aerosol Tethering on Innovative Surfaces in the International Space Station), returned to Earth earlier this year after more than 12 months in space. Previous studies have shown that many types of microorganisms thrive on the space station, with some doing even better in the microgravity environment than on Earth. A NASA study in 2020 also found that the station's microbiome changes as crews rotate, which makes sense – each astronaut brings their own unique set of microbes with them, which then colonise the station's interior.

x2 Images © Getty

Speaking about the weekly cleaning routine, Italian astronaut Samantha Cristoforetti said that astronauts use disinfectant wipes to sanitise handrails, handheld microphones, computers and anything else they touch to minimise their bacterial trail. She further added that "the toughest modules to clean are certainly Node 3, where we have the toilet and the exercise equipment, and Node 1, where we eat".

Astronauts also have to regularly vacuum ventilation grids, which can "get pretty dirty, because all the little debris that floats in the cabin eventually gets taken by the airflow to a return grid," said Cristoforetti. A blocked ventilation grid could impair the station's carbon dioxide scrubbing mechanisms, making the air inside unfit for breathing.



Main: The ISS needs to be maintained weekly to keep spacefarers healthy

Insert: Astronaut Aki Hoshide hard at work cleaning in microgravity

> "WE ALSO HAVE A LOT OF MEASURES ON THE SPACE STATION THAT ARE SIMILAR TO THOSE YOU CAN FIND IN HOSPITALS"
>
> THOMAS PESQUET

TEN YEARS ON

REMEMBERING THE SPACE SHUTTLE

Exactly a decade ago, NASA's reusable low-Earth orbital spacecraft's time came to an end. All About Space relives the best moments

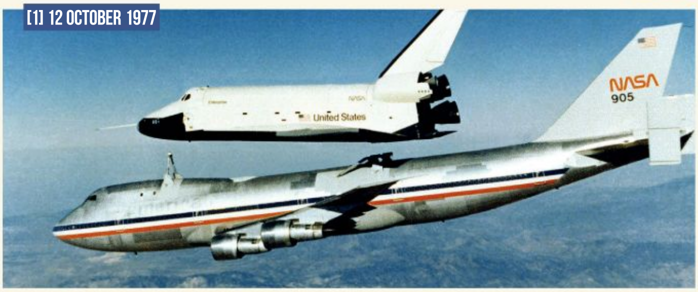
Reported by Stuart Atkinson

At the dawn of the Space Age, when mobile phones, laptop computers and the internet were still the stuff of science fiction, astronauts flew into space crammed inside cramped metal capsules that flew only once, launched on top of rockets that also flew only once. Today astronauts are flying into space inside capsules again, although the reusable Dragon and Orion spacecraft are a lot more sophisticated and a lot less cramped than those that flew during the Mercury, Gemini and Apollo missions.

But for three memorable decades between 1981 and 2011, astronauts travelled into space and worked and lived in orbit inside spacecraft that could be used again and again. These sleek, white spacecraft flew up into orbit like rockets, but landed back on Earth at the end of their mission like a plane, rolling gracefully to a halt on a runway instead of splashing down in the ocean. These were the Space Shuttles.

Designed to be flown dozens of times every year, making access to space reliable and cheap, the shuttles ultimately proved too expensive and sadly too dangerous to keep flying, and NASA returned to using capsules. But for the astronauts who flew them, and the space enthusiasts who whooped and cheered as they leapt off the launchpad and thundered into space, they were and will always be the most beautiful spacecraft ever built.

> "THE SHUTTLES ULTIMATELY PROVED TOO EXPENSIVE AND SADLY TOO DANGEROUS TO KEEP FLYING"


[1] 12 OCTOBER 1977

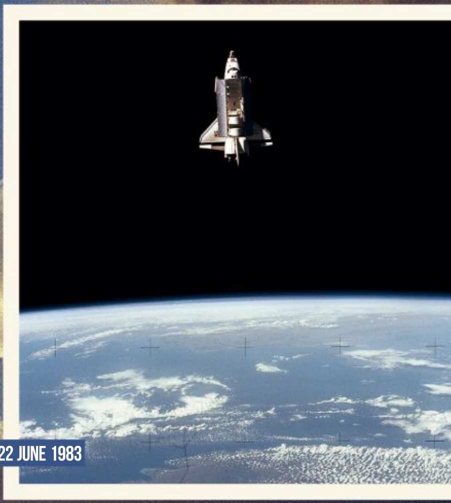
Above: Enterprise during a fourth Approach and Landing Test in October 1977

ENTERPRISE TAKES FLIGHT

1 Before Columbia became the first Space Shuttle to thunder into space in April 1981, another orbiter was used to practise landings. During a series of Approach and Landing Tests, the orbiter was carried into the sky on top of a specially modified jumbo jet. It was then set free, flown and landed on a desert runway by a pair of astronauts. The orbiter was named Enterprise after a fierce campaign by fans of the popular science-fiction series *Star Trek*, but ironically Enterprise never got to fly into space.

FIRST FLIGHT

2 On 12 April 1981, 20 years after Yuri Gagarin's historic flight, the Space Shuttle Columbia thundered into the blue Florida sky for the first time. Carrying just two crew on board – veteran astronaut John Young, who had walked on the Moon in 1972 during the Apollo 16 mission, and rookie astronaut Robert Crippen – Columbia spent just two days in space on a test flight to check out all its systems. Despite some concerns when onboard cameras showed some of its thermal tiles had come off during launch, Columbia returned safely to Earth, gliding down elegantly to a perfect landing.



CHALLENGER FROM ABOVE

Left: Columbia makes her maiden flight into space on 12 April 1981

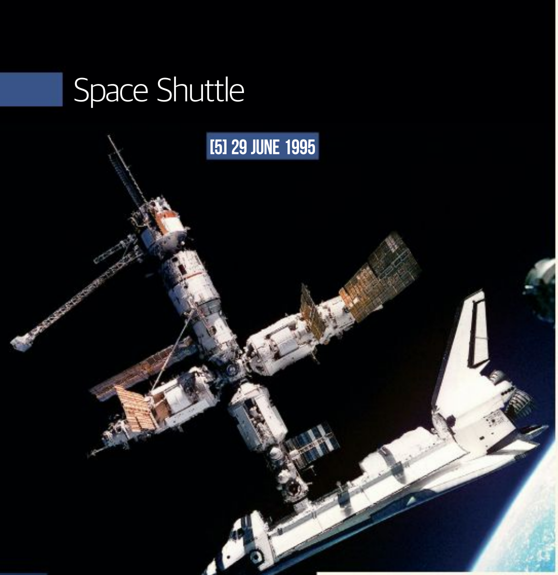
Above: Challenger flying high above Earth on STS-7

3 Although today's crewed Orion and Dragon space capsules are packed with state-of-the-art flight systems, electronics and technology that make them much more advanced than the Space Shuttle in many ways - and safer too - many people think that they are ugly compared to the orbiters.

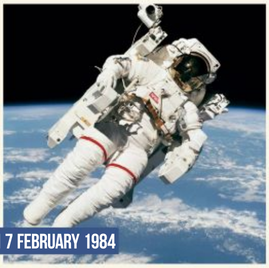
When you see an image like this, showing Space Shuttle Challenger high above Earth, it's not hard to see why. Seen here on the seventh Space Shuttle mission with its payload bay doors open wide and its swept-back wings and tall tail fin gleaming white in the sunlight, Challenger was a spectacular sight. This was taken by a small, free-flying satellite deployed by the Space Shuttle.

TAP HERE TO PLAY

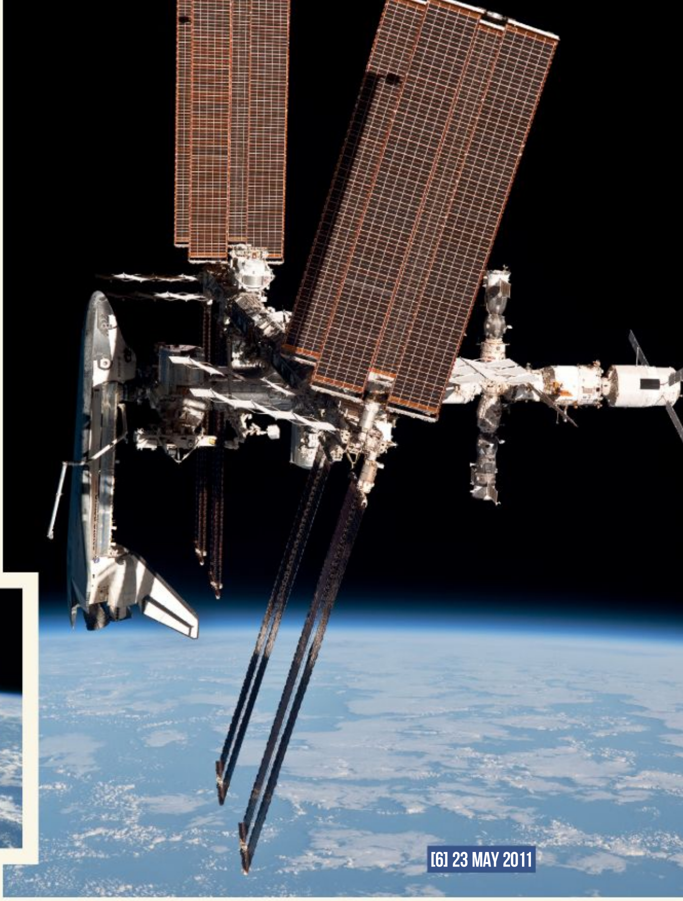
All images © NASA unoess stated otherwise



[5] 29 JUNE 1995



[4] 7 FEBRUARY 1984



[6] 23 MAY 2011

BRUCE MCCANDLESS SPACEWALKING WITHOUT A TETHER

4 Before the Space Shuttle era, every spacewalking astronaut had been connected to their spacecraft by a tether, preventing them from floating off into space. On Space Shuttle mission STS-41-B in 1984, that changed when astronaut Bruce McCandless strapped on a revolutionary kind of 'rocket backpack' called a Manned Maneuvering Unit (MMU), floating up out of Challenger's payload bay without any physical connection to the orbiter at all. As he flew almost 100 metres (328 feet) away from Challenger, propelled by gas jets in the MMU, McCandless was in effect an independent spacecraft. However, the MMU was only used a few more times before being retired, and now astronauts who go out on spacewalks to repair or service the International Space Station (ISS) use tethers.

SPACE SHUTTLE ATLANTIS DOCKED TO THE MIR SPACE STATION

5 One of the major benefits of the Space Shuttle system was the ability of the orbiter to rendezvous and dock with other spacecraft in orbit, and during the Space Shuttle program the orbiter Atlantis paid several very welcome visits to the Russian space station, Mir.

These visits weren't just political gestures like the Apollo-Soyuz Test Project docking of the mid-1970s; they gave ground crews, astronauts and engineers from the two countries opportunities to work together and learn how to collaborate in space in advance of the construction and operation of the ISS, which was built after Mir completed its time in space.

Top left: Space Shuttle Atlantis on one of its visits to the Russian space station

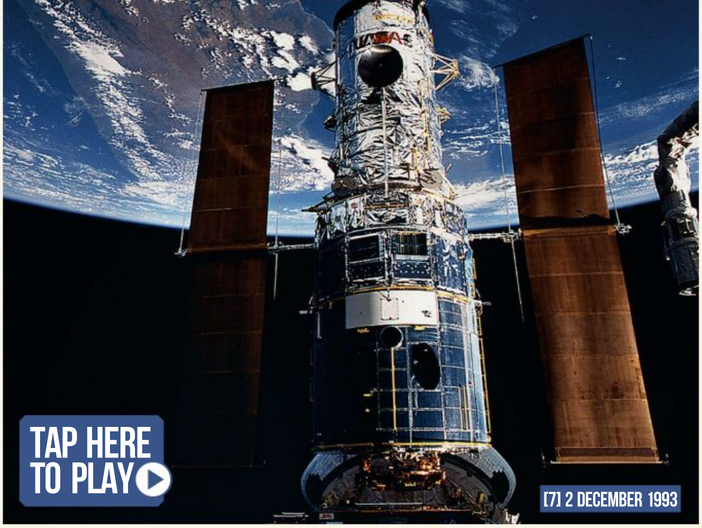
Top right: A Space Shuttle docked to the International Space Station

Above: The first untethered spacewalk during mission STS-41-B

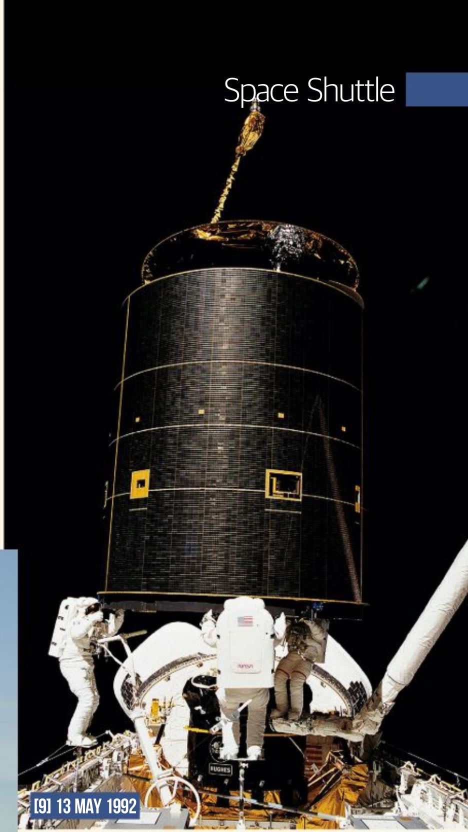
SHUTTLE DOCKED TO ISS

6 Once Mir was retired – by crashing into the ocean in a flurry of blazing fireballs – the ISS began to take shape, and the Space Shuttle became a cross between a cargo ship and a delivery truck, taking various components of the orbital platform into space for the astronauts aboard the space station to fit together, increasing its size and capabilities over time. The shuttle also took astronauts up to the space station and returned them home again. This image shows Space Shuttle Endeavour docked with the ISS. Note how much bigger the ISS is than its predecessor, Mir, and also how much larger it is than the Russian Soyuz spacecraft, which are also docked to the space station. In fact, the shuttle's payload bay could have held a Soyuz with room to spare.

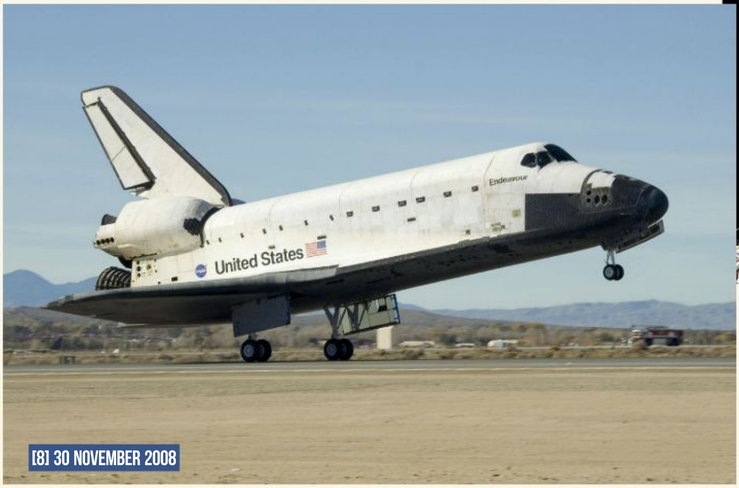
> "THE SPACE SHUTTLE BECAME A CROSS BETWEEN A CARGO SHIP AND A DELIVERY TRUCK, TAKING VARIOUS COMPONENTS OF THE ORBITAL PLATFORM INTO SPACE"



[7] 2 DECEMBER 1993



[9] 13 MAY 1992



[8] 30 NOVEMBER 2008

Top left: Astronauts upgrading the Hubble Space Telescope's instruments during a servicing mission

Top right: Astronauts on Endeavour's maiden flight repair a failed satellite

Left: Endeavour comes in to land at the end of mission STS-126

THE HUBBLE SPACE TELESCOPE RECEIVES AN UPGRADE

7 When Hubble was carried into space on Discovery in April 1990 during mission STS-31, astronomers around the world looked forward to seeing the universe more clearly than ever before. Unfortunately, a fault with the telescope's main mirror meant its images were blurred.

Fortunately for astronomers, spacewalking astronauts, working from another Space Shuttle on a subsequent repair mission, were able to restore Hubble's eyesight by fitting it with corrective lenses.

SPACE SHUTTLE LANDING

8 Although the splashdowns of the modern Orion and Dragon capsules are very dramatic and exciting, they are also a step back to the days when Apollo capsules, blackened and charred from the heat of re-entry, dropped into the ocean beneath billowing red-and-white parachutes. Space Shuttle landings – like Endeavour's at the end of mission STS-126 seen here – were certainly more graceful and less stressful on the astronauts inside.

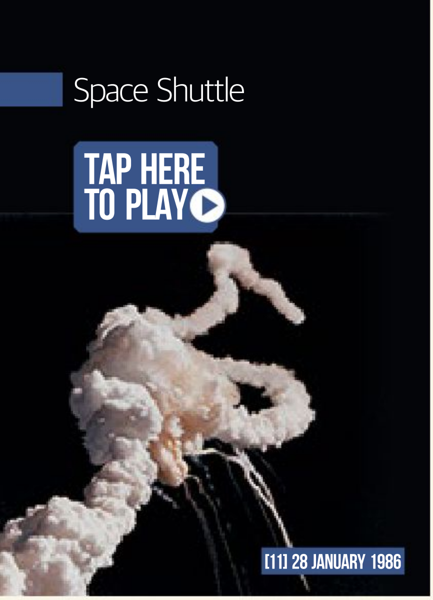
After re-entry the sleek-winged orbiters lined up with the runway – either at a remote desert airstrip or back at the Kennedy Space Center – and were flown down to it just like an aeroplane ending a long flight. At the end of a steep dive the shuttle's nose would rise and its wheels would touch the ground amid swirls of dust before the nose lowered again, the front landing gear touched down and the orbiter taxied to a halt, just like a plane coming in to land at an airport.

SATELLITE REPAIR

9 It's no exaggeration to say that while satellites were once seen as novelties they are now absolutely essential to our everyday lives. They relay our phone calls and TV signals, help us monitor and predict the weather, survey environmental damage and even help us drive to where we want to go.

Before the shuttle era, if a satellite failed in orbit there was nothing that could be done – it was just written off. But several times during the Space Shuttle program, spacewalking astronauts were able to capture and repair broken satellites, saving huge amounts of money, and none of the spacecraft flying or being developed today have that capability.

Here we can see a team of three astronauts working on the Intelsat 603 communications satellite during the maiden flight of Space Shuttle Endeavour on mission STS-49 in May 1992.



[11] 28 JANUARY 1986

[12] 1 FEBRUARY 2003

[10] 30 NOVEMBER 1983

© Alamy

ASTRONAUTS EATING ON BOARD THE SHUTTLE

10 In the early years of the Space Age the food carried into space by the Mercury, Gemini and Apollo astronauts was infamously unexciting and unappetising. Those early astronauts' meals consisted of mushy paste that had to be squeezed out of a tube or a pouch after having water added. Mealtimes on board the Space Shuttle were much more enjoyable thanks to the progress made by NASA's food scientists. While some foods and drinks still came in pouches, many meals were eaten from lap trays, like the meals served on aeroplanes. The food itself was much better too, with Chinese and Italian dishes available, as well as fresh fruit and vegetables and even sweets.

Top left: Space Shuttle Challenger's final flight in January 1986 ended in disaster

Top right: The crew of Columbia pose happily for a photo near the end of their mission

Above: Lunch on the mid-deck of the Space Shuttle

THE CHALLENGER DISASTER

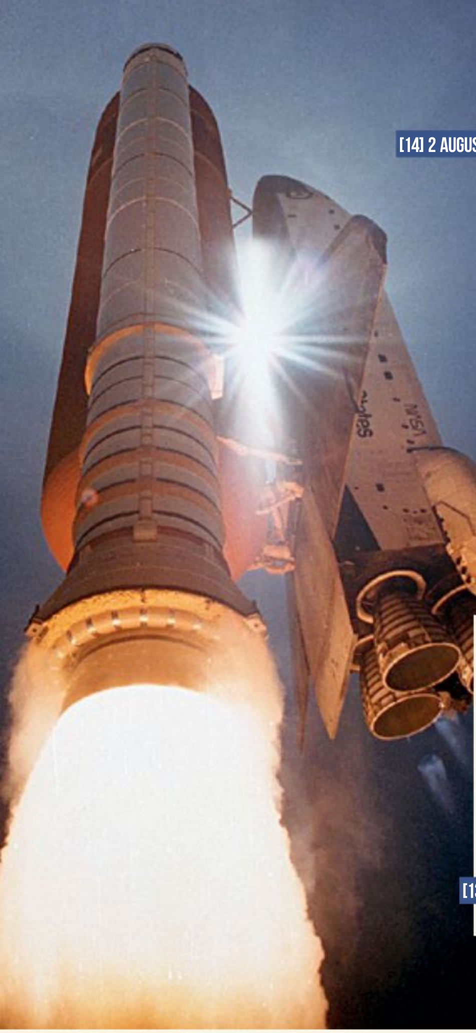
11 On 28 January 1986, 73 seconds after taking off at the start of mission STS-51-L, Space Shuttle Challenger exploded in midair. All seven astronauts aboard were killed, including a civilian, Christa McAuliffe, who had been chosen from thousands of applicants to become the first teacher in space. An investigation showed that a rubber seal inside one of the solid rocket boosters had failed, leading to a fuel leak and explosion. Tragically, it was also found that the astronauts had still been alive - though not conscious - as their armoured crew compartment fell into the ocean and struck the water with enormous force. The Challenger Disaster meant no more shuttles flew for several years until many new safety measures and systems had been introduced.

> "AN INVESTIGATION SHOWED THAT A RUBBER SEAL INSIDE ONE OF THE SOLID ROCKET BOOSTERS HAD FAILED"

THE CREW OF COLUMBIA

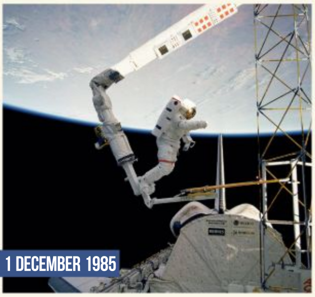
12 When Columbia blasted off on 16 January 2003 at the start of mission STS-107, cameras aimed at the launchpad showed what looked like a puff of smoke coming from beneath one of its wings. The mission went ahead without any further incident, but when the shuttle re-entered the atmosphere at the end of its mission it broke apart into many pieces, trailing smoke and flame across the sky, and all its crew were killed.

Investigations found that a piece of insulation foam had fallen from the huge main fuel tank and struck Columbia's wing, smashing a large hole in it, dooming the vehicle and its crew. The Columbia Disaster led to another delay in shuttle missions, and ultimately to the cancellation of the program.



[14] 2 AUGUST 1991

[15] 10 JULY 2011



[13] 1 DECEMBER 1985

Top left: Space Shuttle Atlantis blasts off on its ninth mission into space

Top right: The Space Shuttle snapped from the ISS

Left: Astronauts practise building structures in space during STS-61-B

CONSTRUCTION SITE IN SPACE

13 Many science-fiction films and books featured astronauts building things in Earth orbit, but on the second flight of Atlantis, astronauts did it for real. During spacewalks in the cavernous payload bay, they practised building a tower and a pyramid out of metal beams and connecting fittings, showing it was possible for astronauts to construct structures in space and setting the stage for the construction of the ISS. Here one of the astronauts is secured to the end of the shuttle's robot arm, surveying the Access Tower built during the long and exhausting spacewalk.

LAUNCH OF ATLANTIS

14 Although the Space Shuttle program had many problems, and the spacecraft themselves had many design flaws, safety and cost issues, it's impossible to watch video footage of one of their launches and not feel awe and wonder at how impressive they looked. The Space Shuttles thundered into orbit from the Kennedy Space Center on top of twin pillars of crackling flames that could be seen and heard for many miles, giving the crews inside a thrilling ride into space. This stunning image of Atlantis launching on its ninth mission in August 1991 offers a fantastic view of the orbiter mounted on the side of its huge, orange external fuel tank, and the pair of solid rocket boosters strapped to its side. It's now many years since the final Space Shuttle launch, but many spaceflight enthusiasts still miss seeing them leap off the launchpad and hope that one day something like them will fly again.

ATLANTIS BLASTS OFF ON THE LAST EVER SPACE SHUTTLE MISSION

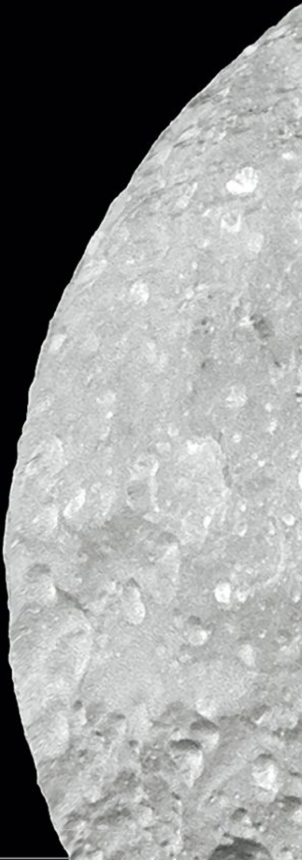
15 Before the program came to an end in July 2011, NASA's Space Shuttles flew 135 missions. Over the course of 20 years its fleet of sleek, white orbiters, all named after famous sailing ships, carried dozens of payloads and hundreds of astronauts from many different countries into space. Shuttles launched satellites and space probes, deployed the Hubble Space Telescope and helped make the ISS the incredible success it is today. It was an incredibly ambitious program, but it proved to be more expensive, less reliable and more dangerous than anticipated, and the fleet was retired.

Today American astronauts fly into space inside SpaceX's Dragon capsules, which look like enhanced, sleeker versions of the Apollo capsules that carried people to the Moon. But the Space Shuttle will always have an important place in space history – and in the hearts of people who remember watching it leaping impatiently into the sky and then gliding back onto a runway on its return, like a swan landing on a lake.

MOON PROFILE

MIMAS

This small, oddly shaped and icy moon continues to baffle scientists



You could be mistaken in thinking this strange satellite is something pulled straight out of the *Star Wars* universe. Commonly referred to as the 'Death Star' moon, Mimas has only been visited a few times, and could be harbouring secrets below its surface.

Discovered on 17 September 1789 by William Herschel, and later named by his son John Herschel, Mimas is Saturn's smallest and innermost major moon. Orbiting just 185,539 kilometres (115,300 miles) above the gas giant, the icy moon zips along at high speeds, completing an orbit in just 22 hours and 36 minutes. Akin to our own Moon, Mimas is tidally locked with its host, meaning it keeps the same face towards Saturn as it orbits the planet.

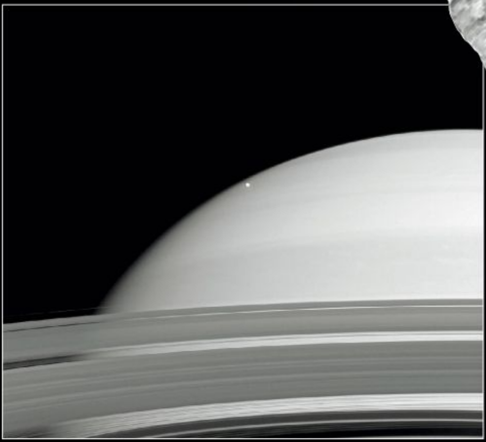
The dinky moon has a mean radius of less than 198 kilometres (123 miles), and as such it is not quite large enough to hold a classic round moon shape. Instead Mimas displays rather odd dimensions of 207 by 197 by 191 kilometres (129 by 122 by 119 miles). The surface of the icy moon is peppered with craters of varying size, with some measuring over 40 kilometres (25 miles) in diameter. The most conspicuous is Herschel, named after Mimas' discoverer, a substantial feature that dominates the landscape and stretches for over 130 kilometres (80 miles).

Some of the moon's formation history can be inferred by the heavily cratered landscape, particularly at the south pole region. Here the craters are generally half the size of anywhere else on Mimas, which would suggest the moon experienced some melting or other resurfacing processes that occurred in this region later than the rest of the celestial body. However, due to limited data and observations of the icy satellite, scientists cannot yet determine the cause of the possible resurfacing.

Mimas continues to perplex scientists with its rather strange composition, as the frozen moon is primarily made from water ice. However, at first glance this composition in itself is not strange, as Mimas is not the only icy moon in the Saturnian system. It is joined by Tethys, Rhea and Dione, as well as Saturn's sixth-largest moon Enceladus, which is thought to possess a liquid ocean below its icy crust.

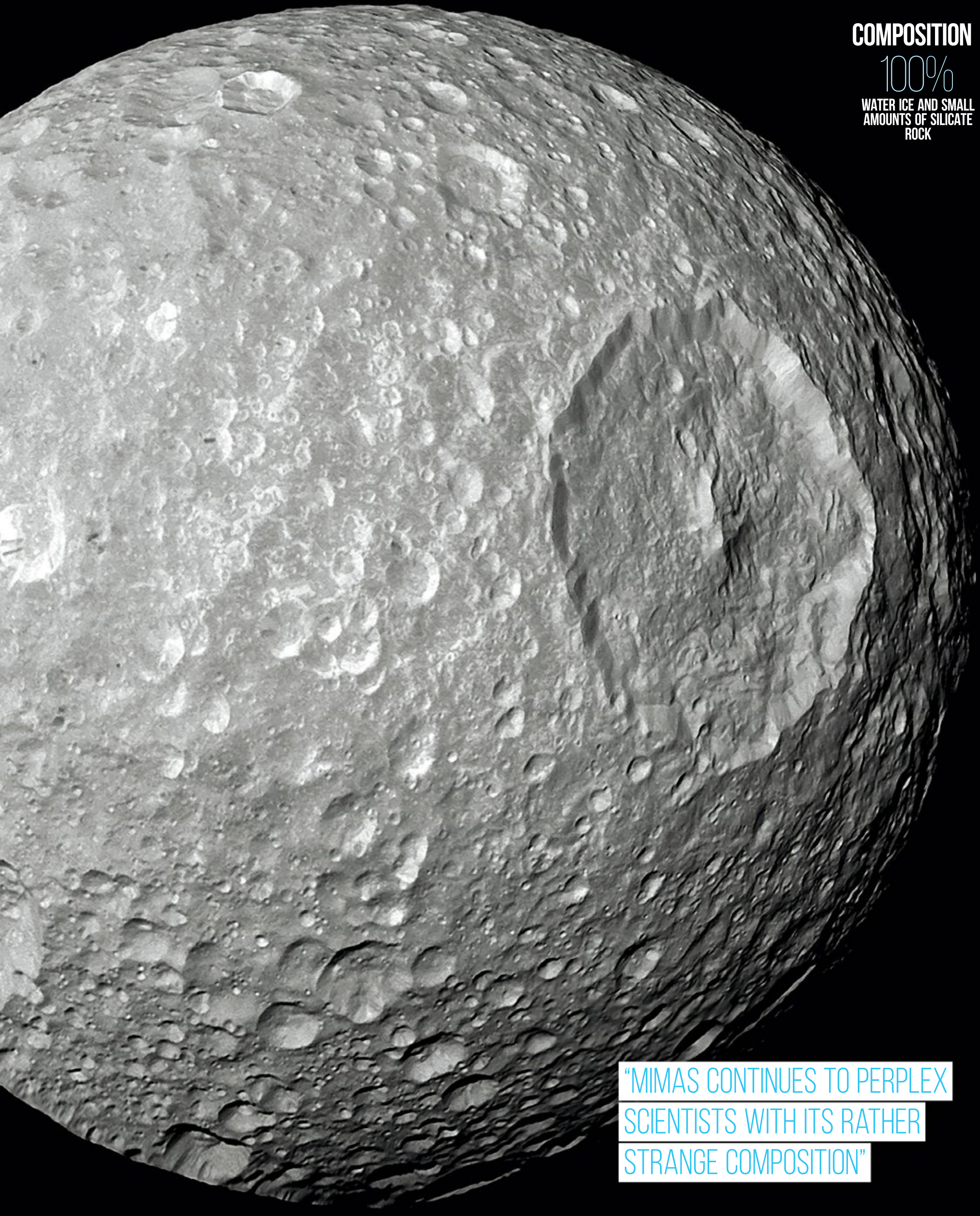
However, unlike these other icy bodies, Mimas is much closer to Saturn and has a far more eccentric orbit. Compared to Enceladus, Mimas should experience more tidal heating due to its position and orbit. However, it's Enceladus that boasts geysers of water that suggest the presence of internal heat, while Mimas remains both frozen and heavily cratered, suggesting that the surface has persisted in this frozen state for a very long time. This paradox has led astronomers to develop the 'Mimas test', by which any theory used to explain the partially thawed water of Enceladus must also explain the entirely frozen water of Mimas.

With its strange dimensions, peculiar composition and quirky appearance earning it a revered place in pop culture, this enigmatic little moon undoubtedly has many more secrets to spill.



Left: This image was taken by Cassini in 2008 shows Mimas against the ring of Saturn

x2 Images © NASA/JPL



COMPOSITION

100%

WATER ICE AND SMALL AMOUNTS OF SILICATE ROCK

> "MIMAS CONTINUES TO PERPLEX SCIENTISTS WITH ITS RATHER STRANGE COMPOSITION"

NEWS FROM MIMAS

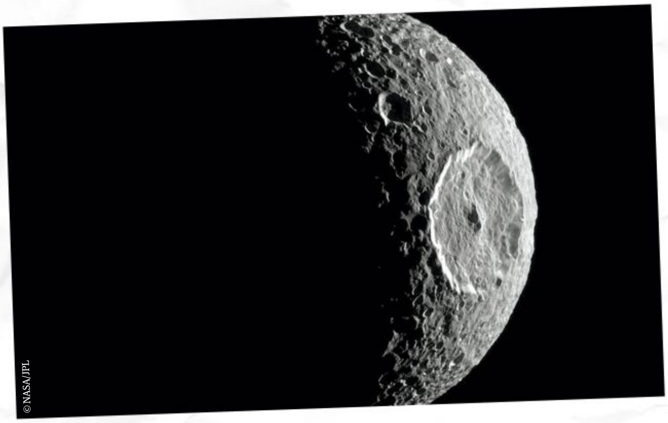
Mimas ploughs through Saturn's rings

Mimas may be the smallest of Saturn's major moons, but it sure is mighty. The tiny, icy body has cleared enough material to create a 4,800-kilometre (2,980-mile) wide gap between Saturn's two largest rings. This void is known as the Cassini Division after its discoverer Giovanni Cassini, who observed it in 1675, and is located between Saturn's A and B rings.

The formation of the Cassini Division had been poorly understood until scientists suggested that Mimas acted as a snowplough, clearing the ice particles that make up the rings from its path and paving the way for the substantial gap.

Mimas is thought to have migrated inwards towards Saturn by approximately 9,000 kilometres (5,600 miles) over a few million years – relatively recently in cosmic terms – leading to the widening of the original gap and the establishment of the Cassini Division. This rift will not last forever, as Mimas has begun to migrate outwards, and in about 40 million years the Cassini Division will have closed up again.

© NASA/JPL


© NASA/JPL

What's behind Mimas' wobble?

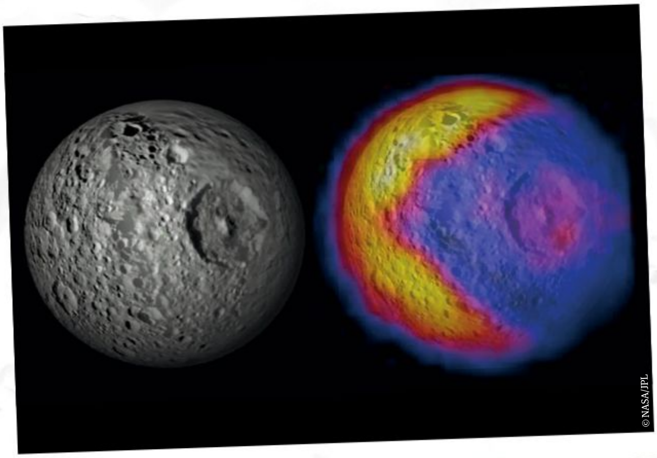
In 2014, scientists analysing data collected from Cassini noticed the moon librates (wobbles) around its polar axis. While this isn't unusual, with libration being observed in many moons, the surprise came when the libration was measured. Mimas' wobble is double than expected and is more pronounced in one spot, suggesting that Mimas' interior is not uniform. Scientists suggested the heavily cratered surface is masking one of two interesting possibilities. One is that the moon contains a rather odd, rugby ball-shaped core, and the other is that there are different materials or densities of material below the icy shell, such as a subsurface ocean.

Since the discovery, scientists have been unable to confirm or deny any of these possibilities, and many questions remain unanswered. If Mimas has an oval-shaped core, we'd expect the moon to take on a slightly different shape to the one we see. And if there's a subsurface ocean, how does Mimas source the heat energy to maintain such an ocean?

Peculiar surface temperatures give rise to a 'Pac-Man' moon

During the Cassini flyby of Mimas on 13 February 2010, an unexpected pattern of daytime temperatures was observed on the little moon's surface. When the Composite Infrared Spectrometer (CIRS) data was analysed and then mapped onto a visible-light image of Mimas, a strange Pac-Man like scene was presented across the moon's surface.

This baffled scientists, who expected to see a uniform distribution of surface temperatures that were highest in the early afternoon, similar to what we see on Earth. Instead Mimas appears to be divided into a warm part (left) and a cold part (right), with a V-shaped boundary between them. Typical temperatures in the warmer region were around -181 degrees Celsius (-294 degrees Fahrenheit), while the colder region saw temperatures drop to -196 degrees Celsius (-320 degrees Fahrenheit). The stark difference between the regions could be due to thermal conductivity of the surface material. If the colder region is made up of surface materials with a higher thermal conductivity, then more of the Sun's heat will be soaked into the subsurface instead of warming the material itself.

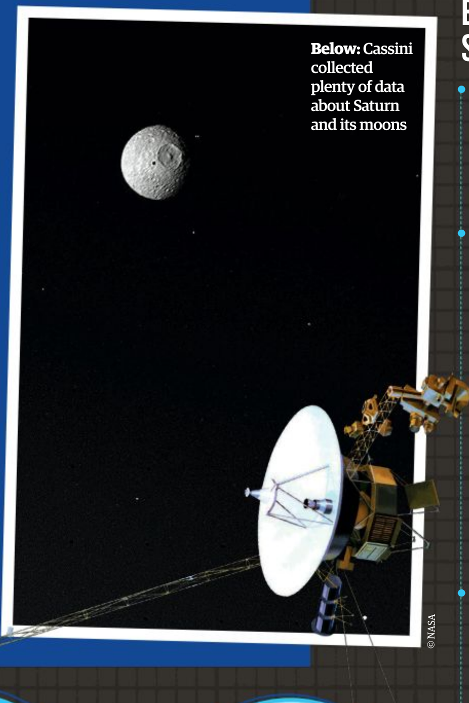

© NASA/JPL

THAT'S NO MOON...

Mimas owes its pop culture fame to its large crater Herschel, which covers one-third of the diameter of the moon itself and gives Mimas its infamous 'Death Star' appearance. The massive crater – named after the moon's discoverer William Herschel – is encompassed by towering outer walls standing five kilometres (three miles) high. At the centre of the crater lies Mimas' mountain, an imposing peak around six kilometres (3.7 miles) high – slightly taller than Mount Kilimanjaro in Tanzania, Africa.

Mimas was lucky not to have been completely torn apart by the colossal impact that spawned this vast crater. Evidence that Mimas was close to breaking point comes from fractures – also known as chasmata – that lie on the opposite side of Mimas. These fissures are thought to have been created by the shock waves generated from a sizable impact, such as the one that created Herschel crater.

Despite the uncanny similarities between Mimas and the Death Star, their resemblance is purely coincidental. While the Death Star first appeared on our screens in the late 1970s, Mimas was not observed in great detail until 1980, when NASA's Voyager 1 spacecraft photographed the satellite from a distance of 550,000 kilometres (340,000 miles).



Below: Cassini collected plenty of data about Saturn and its moons

© NASA

MIMAS BY NUMBERS

22.5 HOURS
The time it takes Mimas to complete one orbit of Saturn

185,539 KILOMETRES
The distance between Mimas and Saturn

198KM
Mean radius of the icy moon

32,038 MILES PER HOUR
Speed at which Mimas orbits Saturn

8.8
How many times smaller Mimas is compared to Earth's Moon

FOUR
The number of spacecraft that have visited Mimas: Pioneer 11, Voyager 1, Voyager 2 and Cassini-Huygens

1789
The year Mimas was discovered by William Herschel

493,647.75 SQUARE KILOMETRES
The surface area of Mimas, slightly less than the land area of Spain

EXPLORATION OF SATURN'S SYSTEM

Date: 31 August 1979
Activity: Pioneer 11 detected Saturn's bow shock – the first conclusive evidence that Saturn has a magnetic field.

Date: 1 September 1979
Activity: Pioneer 11 was the first spacecraft to fly past Saturn. The spacecraft made its closest approach at just 20,900 kilometres (13,000 miles) away.

Date: 12 November 1980
Activity: Voyager 1 became the second spacecraft to fly past Saturn. During its flyby Voyager 1 discovered three new Saturnian moons: Prometheus, Pandora and Atlas.

Date: 26 August 1981
Activity: Voyager 2 became the third spacecraft to fly past Saturn. Data collected by Voyager 2 suggested that Saturn's A ring was only about 300 metres (984 feet) thick.

Date: 1 July 2004
Activity: NASA's Cassini became the first spacecraft to complete an orbit of Saturn.

Date: 26 October 2004
Activity: NASA's Cassini achieved its first close encounter with Saturn's moon Titan. The spacecraft came within 1,200 kilometres (750 miles) of the moon's surface.

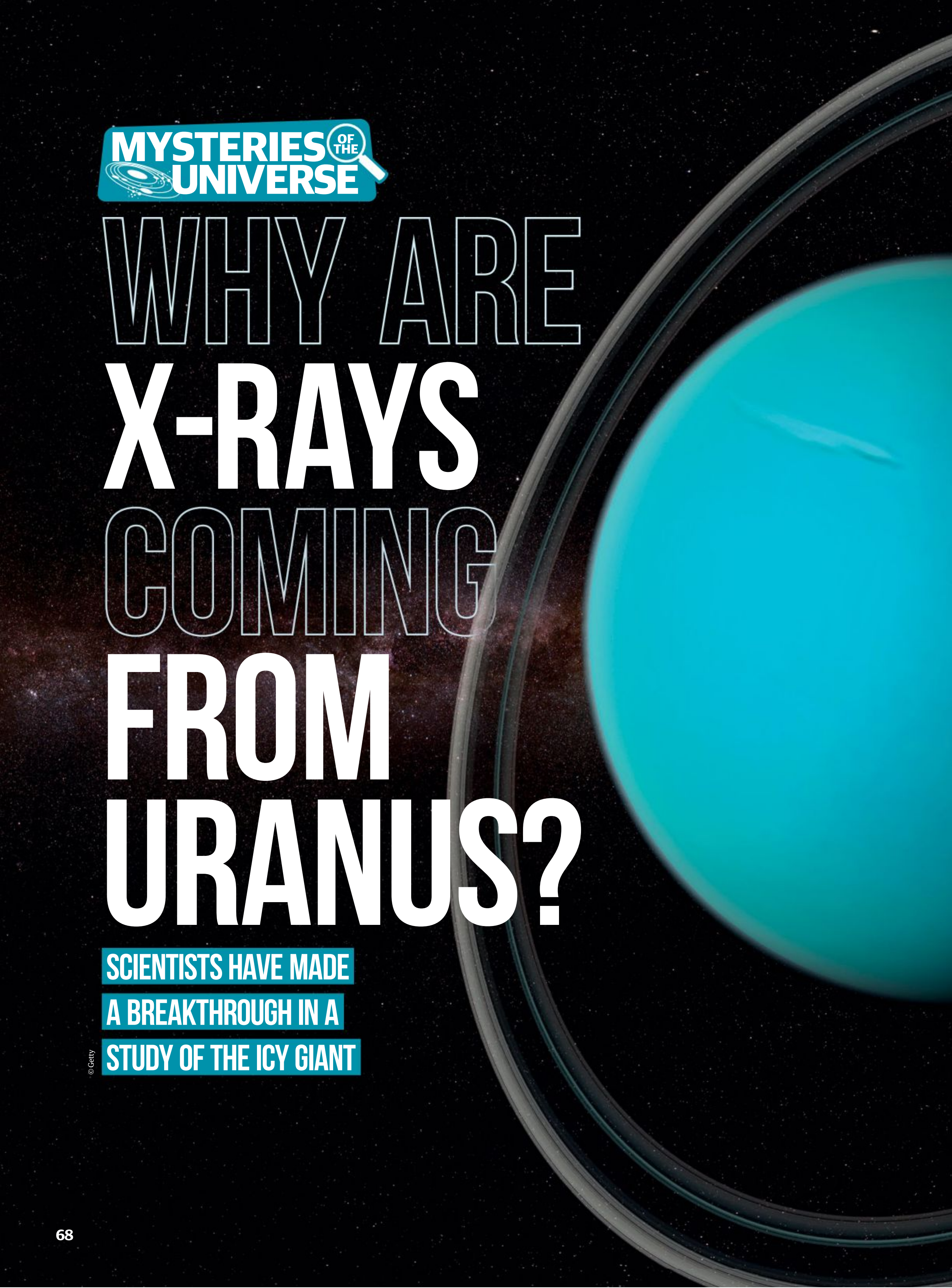
Date: 14 January 2005
Activity: The ESA's Huygens probe successfully landed on the surface of Titan, making it the first spacecraft to make a soft landing on the surface of another planet's moon.

Date: 15 September 2017
Activity: Cassini's mission comes to a dramatic end when it performs a planned plunge into Saturn's atmosphere, beaming back valuable data to the last second.

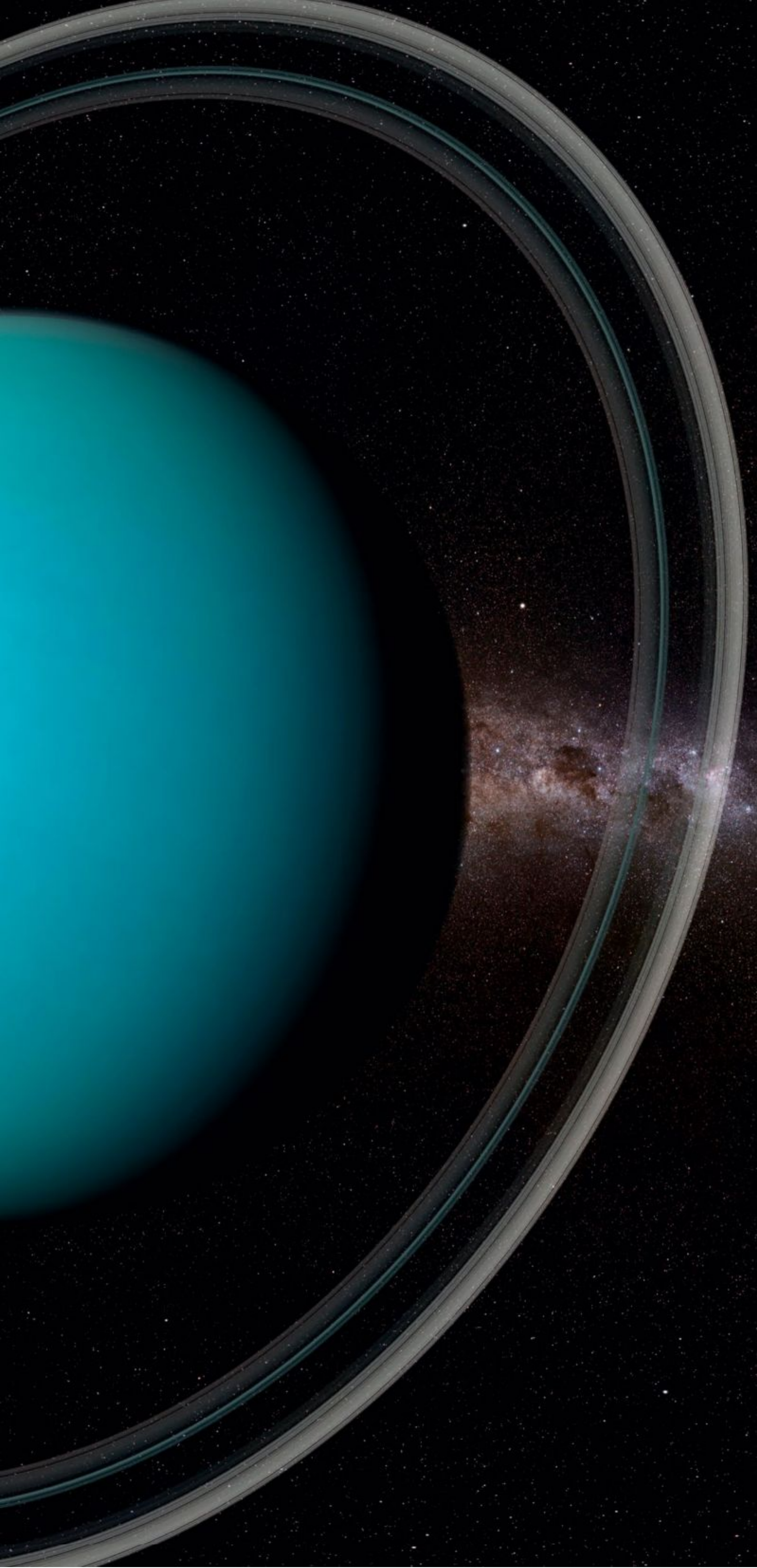
MYSTERIES OF THE UNIVERSE

WHY ARE X-RAYS COMING FROM URANUS?

SCIENTISTS HAVE MADE A BREAKTHROUGH IN A STUDY OF THE ICY GIANT



© Getty



When X-rays were detected from the ice giant for the first time, a team of astronomers began to look into their origin

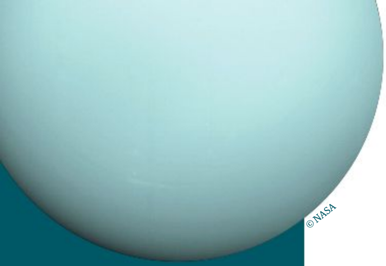
Reported by David Crookes

Uranus has long been thought of as an oddball planet. It's one of two ice giants in the outer Solar System, the other being Neptune, and it's one of two planets to rotate from east to west, the other being Venus. Most strangely, its spin axis is titled by 98 degrees, which means it rotates on its side. And now scientists have discovered something else that's just a little weird.

Data collected by NASA's Chandra X-ray Observatory has allowed astronomers to detect X-rays from the planet for the very first time. For the most part there's a simple explanation for these signals: researchers say one of the sources is reflected emissions from the Sun. But note the word 'one' in that statement, because there also appears to be other sources. What they could be is a mystery, and academics are keen to get to the bottom of them.

Arriving at this point has taken some time. The scientists involved in the latest research have only recently studied observations taken as far back as 2002 by the Chandra X-ray Observatory: one in August 2002 and two in November 2017. They found that the first observation detected X-rays, while the second two detected a flare of X-rays. But why has it taken so many years to make such an exciting discovery about one of the Solar System's most enigmatic planets?

"The signal from Uranus is really dim, so we had to do lots of tests to check that it was genuine," says Dr William Dunn, a research fellow in the department of space and climate physics at University College London (UCL). "In fact, after a first cursory look at the data in 2017, I started drafting a paper titled *No detection of X-rays from Uranus*. Fortunately, I did a bit more digging into the data."



© NASA

URANUS
BY NUMBERS

84
Length of a Uranus year in Earth years

19.8
Distance from the Sun in astronomical units

27
Number of known moons

4
Number of ringed planets in the Solar System

30
Max number of kiloseconds of each Chandra X-ray observation

7
Number of planets where X-ray emissions have been detected

2002
Year the first X-ray observation from Uranus was made

1
spacecraft has visited Uranus: Voyager 2

© Nichoas Forder

HOW NASA'S CHANDRA X-RAY OBSERVATORY GATHERED DATA ABOUT URANUS

Astronomers made their breakthrough by analysing three sets of information collected by this amazing spacecraft

Dunn was still at school when the first observations were taken. "But I guess that when those observers took the observations - without all our subsequent knowledge from Jupiter and Saturn - the X-rays from Uranus looked a lot like the background emission, and so it was assumed - very reasonably for the knowledge at the time - that it was a non-detection," he says.

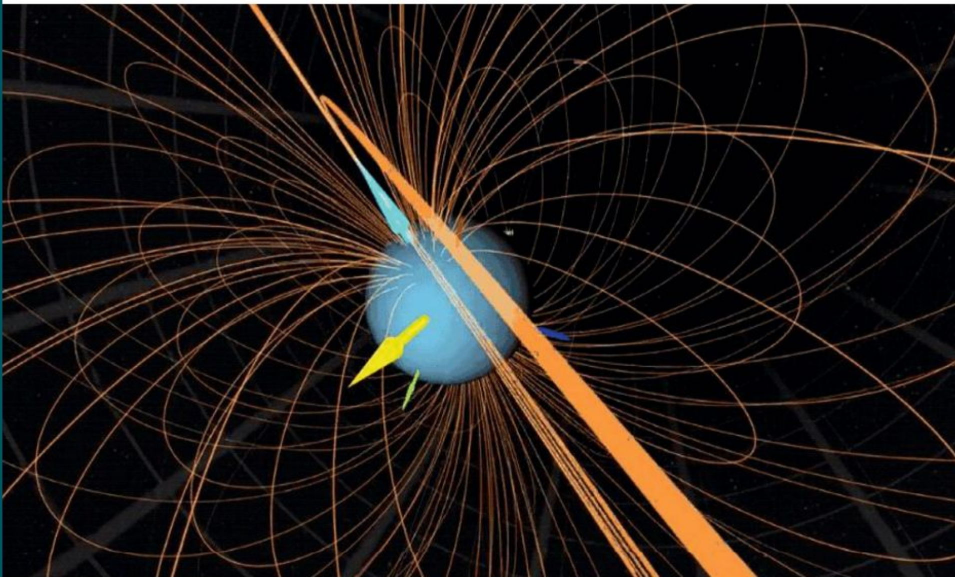
Since then astronomers have learned so much more about the outer planets - in particular Jupiter and Saturn - and it was the lessons which emerged from such studies that led a group headed by Dunn to re-examine the 2002 data in a new light. "In particular, it lets us throw away lots of background noise that we now know is not produced by planets," Dunn continues. "Being able to filter that out of the observations was critical to revealing the planetary signal. Without being able to throw away the noise [X-rays with very high energies], it would be very difficult to detect the planet."

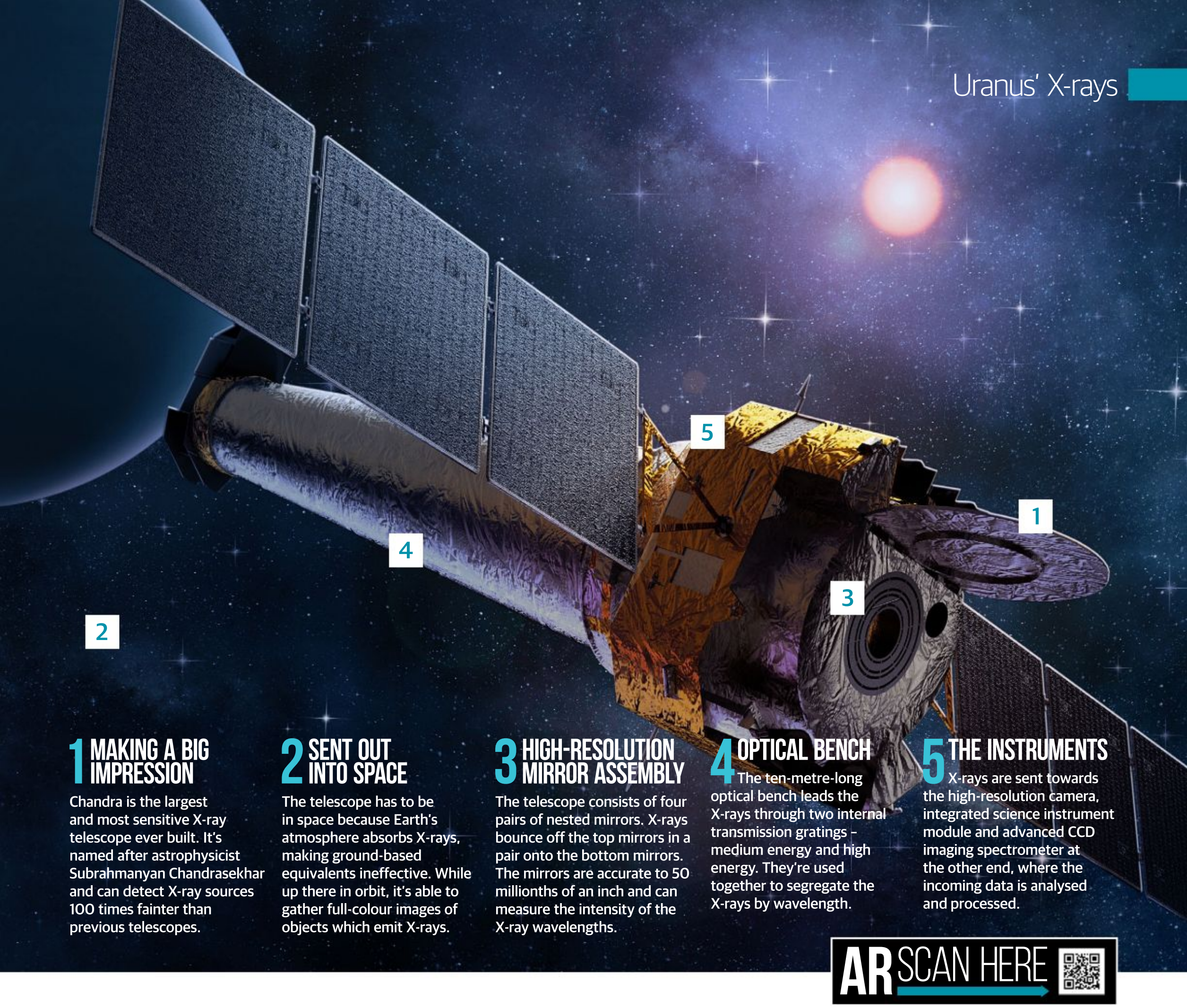
By observing Jupiter and Saturn, astronomers have noted that the planets scatter X-ray light given off by the Sun. They do so because their atmospheres have lots of hydrogen in them, making them really good at reflecting X-rays from our Solar System's star. Other objects also emit X-rays, from Venus to the moons of Jupiter.

"If a big solar flare goes off on the Sun, then the whole of Jupiter and Saturn brighten up with it, and the brightening lasts the same amount of time as the solar flare lasts, although we have to wait a couple of hours for the light to get from the Sun to Jupiter and Saturn and then back to us," Dunn explains.

Uranus also has hydrogen in its atmosphere, albeit to a slightly lesser extent than on Jupiter

Below: This image gives an idea of Uranus' magnetic field. The yellow arrow points to the Sun and the blue arrow shows the planet's magnetic axis





1 MAKING A BIG IMPRESSION

Chandra is the largest and most sensitive X-ray telescope ever built. It's named after astrophysicist Subrahmanyan Chandrasekhar and can detect X-ray sources 100 times fainter than previous telescopes.

2 SENT OUT INTO SPACE

The telescope has to be in space because Earth's atmosphere absorbs X-rays, making ground-based equivalents ineffective. While up there in orbit, it's able to gather full-colour images of objects which emit X-rays.

3 HIGH-RESOLUTION MIRROR ASSEMBLY

The telescope consists of four pairs of nested mirrors. X-rays bounce off the top mirrors in a pair onto the bottom mirrors. The mirrors are accurate to 50 millionths of an inch and can measure the intensity of the X-ray wavelengths.

4 OPTICAL BENCH

The ten-metre-long optical bench leads the X-rays through two internal transmission gratings – medium energy and high energy. They're used together to segregate the X-rays by wavelength.

5 THE INSTRUMENTS

X-rays are sent towards the high-resolution camera, integrated science instrument module and advanced CCD imaging spectrometer at the other end, where the incoming data is analysed and processed.

AR SCAN HERE

© NASA

> "THE SIGNAL IS REALLY DIM, SO WE HAD TO DO LOTS OF TESTS TO CHECK THAT IT WAS GENUINE"
>
> WILLIAM DUNN

and Saturn. It's this which has led astronomers to believe the Sun is involved in the detection of X-rays on Uranus, but whether or not it's a main cause remains uncertain. "I don't think we know that it's a main cause," Dunn says. "It's certainly a cause, but we only have three exploratory observations, and there are hints that some of the emission came from elsewhere."

As it stands there appears to be two possibilities for the detection of X-rays on Uranus, aside from them being reflected emissions from the Sun. The first explanation is that scientists are observing X-ray aurorae like we see on Jupiter and here on Earth, although they're not sure what would trigger them on Uranus.

Aurorae manifest themselves as colourful light shows, and they're linked to charged particles within the magnetosphere. On Earth and Jupiter, energetic electrons travel down the magnetic field lines to the poles and are slowed by the atmosphere. On Jupiter they're also caused by positively charged atoms and molecules raining down on the poles.

"We know that Uranus has a really bizarre magnetic field: the field is tilted to the rotation axis by a huge amount, and it doesn't even seem to go through the middle of the planet – it's offset somehow to one side, and it doesn't look like the bar magnet [dipole] situation we're familiar with for Earth, Jupiter and Saturn. Instead it's multipolar. This creates some really crazy interactions between the planet and the particles that stream out of the Sun," explains Dunn.

"Auroral emissions will relate to this somehow, but we have so little data from measurements in this environment – the only measurements we have are from when the Voyager spacecraft zipped past the planet in 1986 – that I would not like to yet guess at what process causes it. I think to truly answer this, we'll need to send a spacecraft back to

Left: Chandra has made many breakthroughs. Here it is seen being checked over a few months before it was launched in 1999

Below: This image of the Sun shows a stream of X-rays. These will be reflected off the atmosphere of Uranus

© NASA

the planet to orbit it and see the evolution of the environment around the planet."

The second possibility is that researchers are observing X-ray fluorescent glowing from the rings when electrons and protons which surround Uranus in nearby space smash into them. "There could be more going on, because everything we know right now is based on just these very short exploratory observations," Dunn continues.

But what is prompting scientists to think the Sun isn't the primary cause of the X-rays? Quite simply, there appear to be more X-ray emissions from Uranus than would be expected solely from the planet's atmosphere. "This was a surprise," says Dunn, "And to explain why we have to consider what happens on other planets."

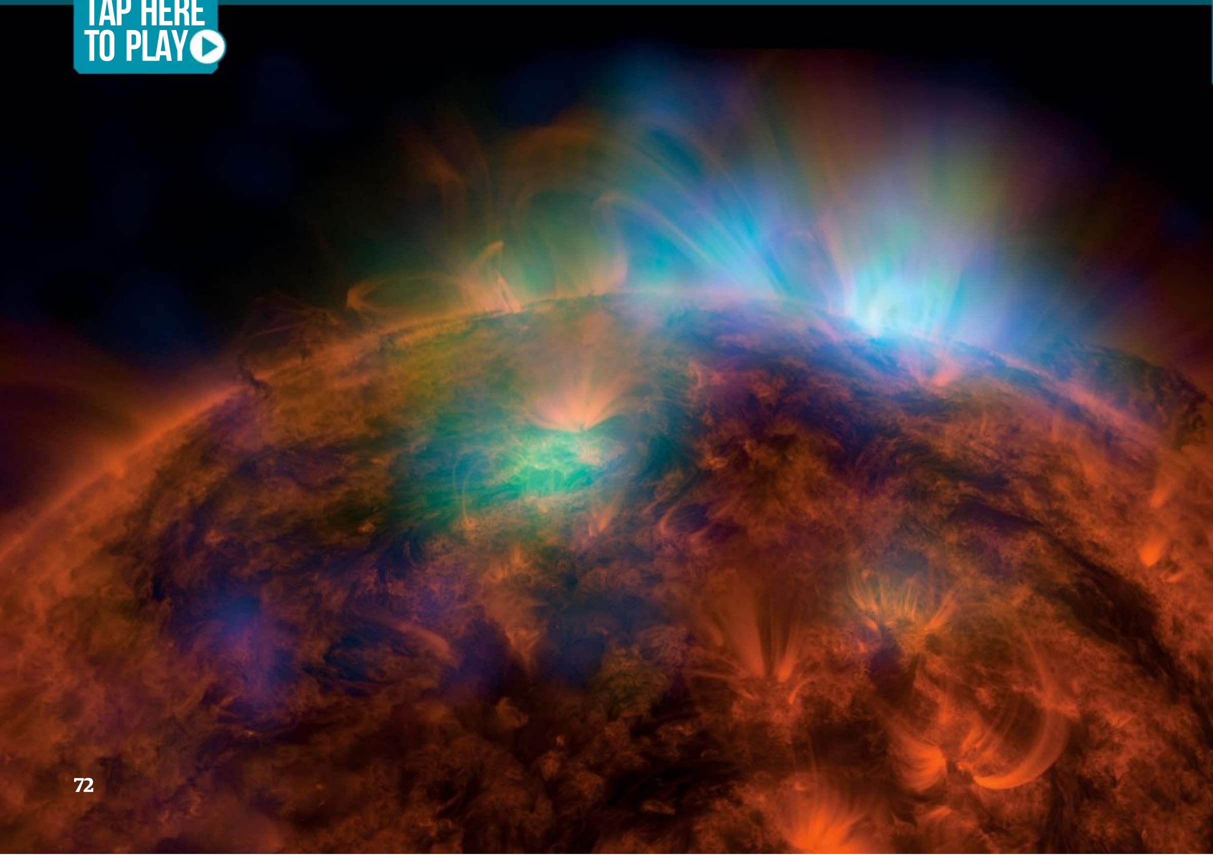
He first draws attention to Jupiter, which has the strongest planetary magnetic field. "It spins faster, and its poor tiny moon Io is the most volcanic body in the Solar System, pumping a tonne of volcanic material into the space around Jupiter every second," he says. "All of this creates crazy energetics and produces bright X-ray emissions, particularly bright flares from the aurorae."

He then discusses Saturn, which was better observed when cutting-edge instruments were developed in the early 2000s. "People may have expected similar dynamic and bright auroral X-ray flares and things like that, but actually we've still not seen X-ray aurora from Saturn, and we've tried a few times now."

Saturn does, however, have some cool stuff: water in its rings glows in X-rays when particles hit. "But mostly Saturn seems a bit X-ray boring. It seems to mostly just reflect the Sun's emissions."

With that in mind, the scientists expected Uranus to be like Saturn. "Just some scattered emission from the Sun and for it to be a bit boring," Dunn laughs. But that is not happening. "Uranus is potentially throwing a spanner in the works here. If Uranus is making X-ray aurorae, then there are some crazy energetics going on for the ice

TAP HERE TO PLAY



giants despite them being smaller than Saturn and rotating much slower."

Dunn says that we already knew this to a degree. In 2010 Barry Mauk and Nicola Fox showed that Uranus has a higher intensity of near 100 kiloelectronvolt electrons than Jupiter or Saturn and near-identical intensities of megaelectronvolt electrons. "They showed there were lots of energetic particles smashing around in the space around Uranus," Dunn continues. "I just don't think we'd quite connected the dots as a community."

Yet what if there is a mistake? What if the extra X-rays are not coming from Uranus at all, but somewhere else in the detector's view? The scientists have certainly thought of that, and they have spent a lot of time – many months, in fact – checking the data to ensure that they haven't missed something that would skew their conclusion and lead to another answer.

"In the end it turned out that it's rarer than a one-in-a-million chance that the signal that we see from Uranus is randomly generated by the detector or the night sky," Dunn says. "It could well be that we got unlucky and hit that one-in-a-million chance, but the energy of X-rays looks so much like they do from Jupiter and Saturn that it is even less likely than that.

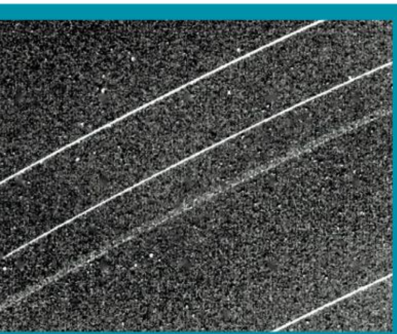
"Not only would the detector or sky need to randomly generate the signal, it would also need to randomly produce photons of the same sorts of colours we see from Saturn and Jupiter. Again though, we probably need some more observations just to double-check that this wasn't a one-in-a-million happening."

And that is where we are today. From this point on there will be a proposal for more X-ray observations using Chandra or its sister X-ray observatory XMM-Newton. "That will involve the scientific community determining whether our case is more compelling than all of the other amazing science cases that they'll receive – there's lots of fantastic science that these instruments enable, and unfortunately there isn't enough time for all of it," Dunn laments.

One thing's for sure, however: the scientists are going to need a much longer period of observation. "The three observations that the discovery is based on are all far too short to answer most of the questions being asked. What we'd ideally like is a few long observations so that we can see how the planet changes over a few rotations and collect enough data to answer those questions."

Ultimately, a new spacecraft is needed to allow scientists to get up close and personal with the ice giants. So far only Voyager 2 has flown to Uranus, so there's an over-reliance on telescopes. Given the distance between us and the outer planets, it's far from ideal, although future technology such as the European Space Agency's Advanced Telescope for High Energy Astrophysics (ATHENA), due to launch in 2031, may help.

"We need spacecraft orbiting these exotic and mysterious worlds to truly understand them, especially because it looks like ice giants are some of the most common planets in the universe," concludes Dunn, whose team's findings are detailed in a paper in the *Journal of Geophysical Research*. "As it stands we have these two fantastic examples in our own Solar System, but we know so little about them."


© NASA

© NASA/JPL-Caltech

Above: When energetic particles smash into the rings of Uranus, X-rays may glow as a result

"URANUS IS POTENTIALLY THROWING A SPANNER IN THE WORKS HERE"

WILLIAM DUNN

David Crookes

Science and technology journalist

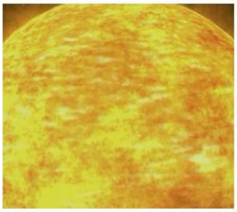
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

THE THEORIES

What could be causing the X-rays from Uranus?

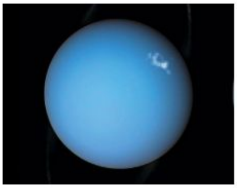
THE SUN

Jupiter's X-rays are synchronised with the Sun's emissions, and astronomers have discovered that the gas giant's glow is due to the X-rays from the Sun reflecting back off the planet's atmosphere. That's happening on Uranus, too, but it's not thought to be the sole explanation.


© NASA

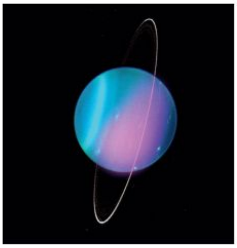
AURORAE

Aurorae light up Uranus' atmosphere, and they're driven by the same processes as on Earth: by streams of charged particles like electrons which become caught in powerful magnetic fields. Scientists are not sure what causes aurorae on Uranus, but they may be a source of extra X-rays.


© NASA

URANUS' RINGS

There are charged particles such as electrons and protons all around Uranus, and it may well be that they are colliding with the two sets of rings that loop around the planet's equator, causing material in the rings to glow and emit X-rays.


© NASA

ASK Space

Our experts answer your questions

© NASA/ESA

ASTROPHYSICS

What are gamma-ray bursts?

Gamma-ray bursts are the biggest explosions in the universe, caused by the death of a massive star or the merger of two extremely dense objects, such as neutron stars or black holes. The outcome at the centre of these extremely explosive events is most likely a black hole.

An enormous amount of energy is released, as much as the Sun produces during its entire lifetime. This vast amount of energy powers the fastest outflows of matter in the universe and a very bright yet short-lived source of light.

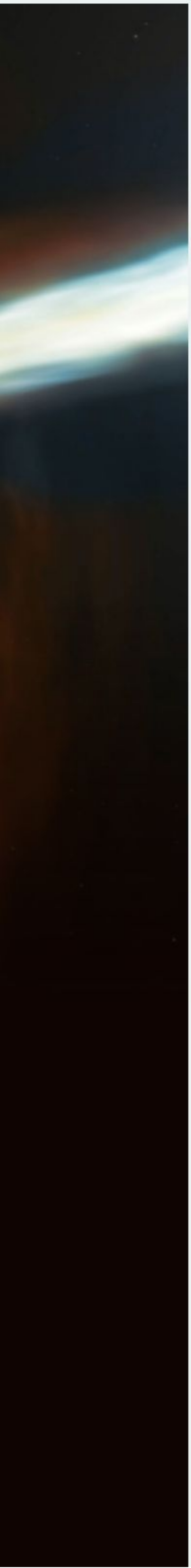
Gamma-ray bursts are named after the short flashes of gamma rays they produce, which for a few seconds outshine all the other gamma-ray sources in the universe. They also produce other forms of light, such as X-rays, visible and infrared light and radio waves, and some of them can produce gravitational waves.

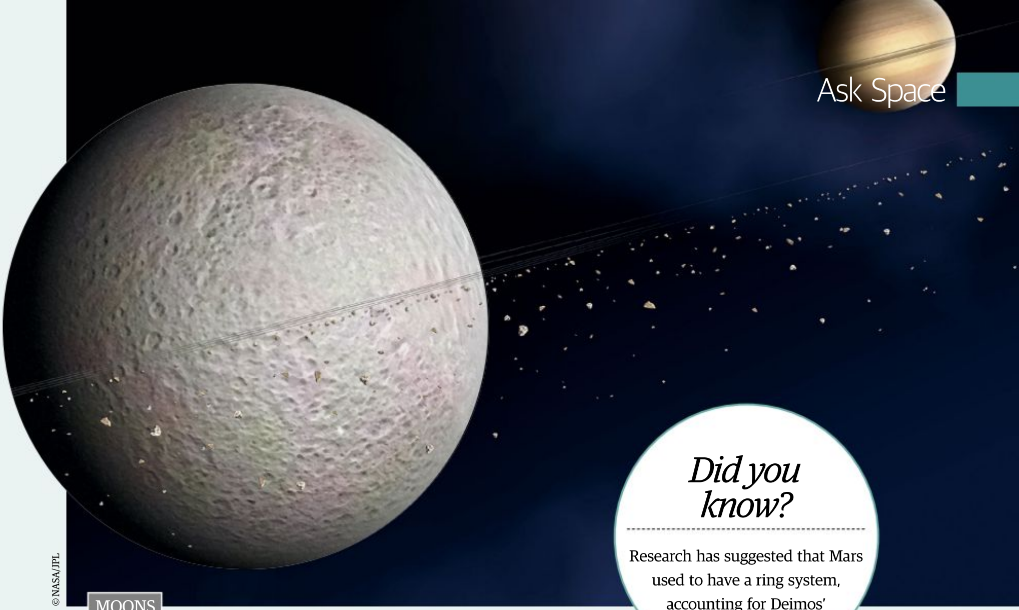
Astronomers use these observations to study physics under the most extreme conditions and the galaxies that harbour gamma-ray bursts throughout the entire universe up to billions of light years away. They are truly the most extreme physics laboratories in the universe.

Alexander van der Horst, associate professor of astrophysics at the George Washington University

Above: Illustration of a powerful gamma-ray burst, GRB 190114C

> "THE OUTCOME AT THE CENTRE OF THESE EXTREMELY EXPLOSIVE EVENTS IS MOST LIKELY A BLACK HOLE"
>
> ALEXANDER VAN DER HORST





© NASA/JPL

Did you know?

Research has suggested that Mars used to have a ring system, accounting for Deimos' tilted orbit.

MOONS

Can a moon have rings?

A-rings, like the ones belonging to Saturn, are made of a mix of particle sizes orbiting their host. Having something like that around a moon is not very likely. Rings are usually caused by material from a massive disruptive event being caught in orbit – possibly a small object being ripped apart by gravity or material from an impact. Gas and rocks of varying size form a cloud and then a disc. The gas disappears, leaving boulders behind that collide and create a mix of different-sized material

The particles are small and easily disturbed. Saturn's rings show this nicely: Shepherding moons clear gaps in the rings and cause beautiful wave patterns. A ring system needs to have a stable gravitational environment, and a moon most likely can't offer this since its planet would throw its ring system out of kilter.

Rhea was briefly suspected to have rings, but this was ruled out in 2010 as they couldn't be directly observed. Some asteroids and even a dwarf planet with a calmer gravitational environment around them are suspected to have rings, but again these have only been indirectly observed.

Dr Daniel Brown, associate professor in astronomy at Nottingham Trent University

Above: Artist's concept of possible rings around Rhea

Below: An image of northern Europe taken from the International Space Station

COSMOLOGY

Why is space black?

The darkness of our night sky tells us more about the size, age and nature of the universe than we may expect. We are familiar with the twinkling of nearby stars in the night sky, but why does the night sky not glow with the colour and brightness of the average star?

If the universe is infinite in size and age, then in every direction there should be a star or galaxy, well known to be powerful emitters of visible light. This puzzle is known as Olbers' paradox. The first part in resolving this is that the universe must have a finite age. This means only a finite number of stars can be observed from Earth in any direction – true even if the universe has infinite size.

The second part is from the expansion of the universe, part of our understanding of cosmology known as the Big Bang model. This expansion of space, together with a finite light travel time, causes the radiation emitted in this hot, dense beginning, as well as that from distant stars and galaxies, to be shifted to longer wavelengths than are visible to the naked eye. The night sky is dark to us due to the expanding, evolving and finite age of the universe.

William Alston, European Space Agency

© NASA

© NASA

ASTROPHYSICS

Why are radio galaxies important?

They help us to understand how galaxies have changed throughout the cosmic history of the universe. Most galaxies have a supermassive black hole at the centre, millions of times the mass of our Sun. In radio galaxies, 'stuff' is falling into the supermassive black hole.

It's gorging itself on gas and dust and generally wreaking havoc. Enormous amounts of energy are released, and sometimes huge jets of plasma grow out of either side of the galaxy. Think of a water jet from the blowhole of a whale. It comes out in a narrow column, then turns into a cloudy plume. That's more or less what the plasma jets look like.

The plasma jets glow in radio light, which can be seen with radio telescopes. This is why these systems are called radio galaxies. The plasma jets can heat up the gas in the rest of the galaxy or completely blow it out. This essentially 'kills' the galaxy, because without cold gas it cannot form new stars.

Studying the way these jets change the galaxy helps us understand why galaxies look the way they do today and why they looked different in the past.

Dr Jacinta Delhaize, SARAO postdoctoral fellow at the University of Cape Town

SOLAR SYSTEM

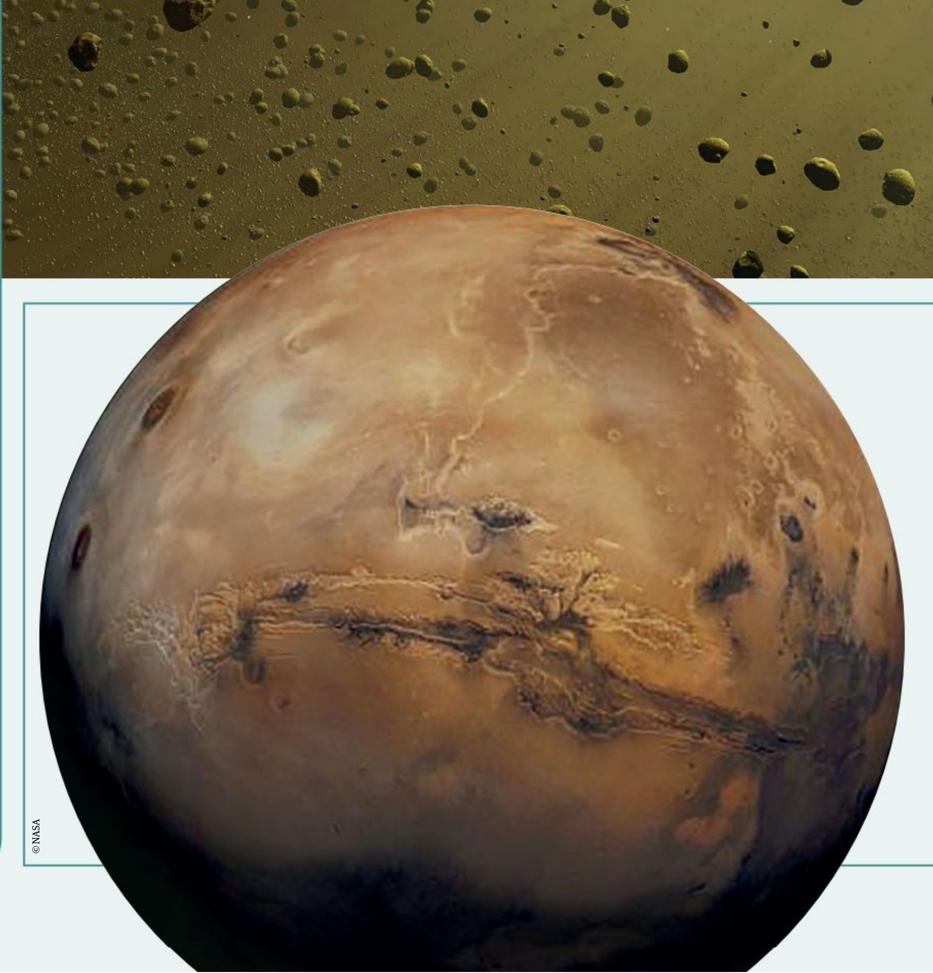
Is our Solar System big or small in comparison to others?

Neptune is much farther away from the Sun than most known exoplanets are from their parent stars. In this sense the Solar System is wider than most other known planetary systems. However, this blanket statement comes with a few caveats.

First, our observations are biased. We can more easily find exoplanets close to their stars, which means that with current technology many exterior planets probably remain hidden to our telescopes. Also, nearly all exoplanets which have been found represent our nearest stellar neighbours within the Milky Way. Only rarely can we observe planets beyond our neighbourhood. The Solar System might be wide compared to our neighbours, but not wide compared to all planetary systems.

Finally, the size of our Solar System itself is subject to interpretation. Neptune might be the most distant planet, but planetoids like Sedna are three times farther away, and many comets are 3,000 times farther away. We expect that the maximum gravitational reach of the Sun is comparable to that of other planetary hosts, which would not make our Solar System particularly wide at all.

Dr Dimitri Veras, associate professor and STFC Ernest Rutherford fellow at the University of Warwick



© NASA

Left: An artist's impression of a distant, hypothetical solar system that is a similar age to our own

©NASA/JPL-Caltech

Did you know?

Eight planets have been found in orbit around the Sun-like star Kepler-90 – the same as around our Sun.

PLANETS

Can a planet orbit a star in the opposite direction to all the other planets in a solar system?

This would be very unlikely. Planets usually all orbit their star in the same direction – the direction of rotation of the central star. The reason is that when the system is forming, it's a big cloud of gas and dust in rotation. The protostar starts to form at the centre under the action of gravity.

At the same time the cloud is flattening into a disc, and material starts to accumulate and form aggregates. They collide into each other and grow in size as they keep orbiting the star.

These aggregates – or protoplanets – will become full planetary bodies and form the planets we know today, still orbiting in the same direction that only gas and dust particles used to follow billions of years ago. We could imagine, however, that a planetary body could be captured long after the formation of the system and end up orbiting in the opposite direction of the other planets.

Scientists have also identified a few cases of planets orbiting in opposite directions in extrasolar systems. This is the result of complex interactions of gravity forces of the star and other massive planets in the system and is very rare.

Ines Belgacem, European Space Agency science research fellow

SPACE EXPLORATION

Is there a way that humans could have an effect on other planets' climates, for example if humans went to Mars?

Humanity at the moment as a species – an industrial civilisation – is inadvertently driving climate change on Earth. There are activities that are changing our very environment. People are now talking about doing that deliberately, but only if we can work out how to do those processes in a controlled way.

There has been talk of doing it to other planets, such as Mars, and this is called 'terraforming'. How can you change the environment of Mars to make it more habitable and more hospitable for people to live in? How can you start pumping up its atmosphere? How can you start getting a stronger greenhouse effect on Mars to warm its surface so that water can flow again? How can you start introducing and producing oxygen on Mars? People talk about those sorts of processes being applied deliberately to Mars so humans – in the far future – can live there.

© Getty

Lewis Dartnell, professor of life sciences at the University of Westminster

Far left: A compilation of images captured by Viking 1 make up this mosaic of Mars

Right: Artist's impression of TRAPPIST-1 and its planets

© NASA

WHAT'S IN THE SKY?

IN THIS ISSUE...

78 What's in the sky?
Our guides will help you make the most of the short and bright summer nights

82 Month's planets
Venus takes pride of place as an evening star, dazzling at an impressive magnitude

84 Moon tour
Take an imaginary trip to the site of the first lunar base - in both fact and fiction

85 Naked eye and binocular targets
The summer sky is bright, but there are still things to see

86 Deep sky challenge
Glittering star clusters, a dead star and a beautiful double star await

88 The Northern Hemisphere
The central part of our galaxy is teeming with star clusters

90 Astroshots of the month
The best of our readers' astrophotography

92 Telescope review
We put the Celestron NexStar Evolution 8 to the test

96 In the shops
Our pick of the best products for astronomy and space fans

> "AN OBJECT'S MAGNITUDE TELLS YOU HOW BRIGHT IT APPEARS FROM EARTH"

RED LIGHT FRIENDLY

In order to preserve your night vision, you should read our observing guide under red light

18 JUN
Comet 15P/Finlay makes a close approach to Earth at a predicted +8.7 in Pisces

18 JUN
Open cluster IC 4665 is well placed for observation in Ophiuchus at +4.2

Source: Wikipedia commons © Roberto Mura

27 JUN
Conjunction between the Moon and Saturn in Capricornus

27 JUN
The June Boötids meteor shower reaches its peak

27 JUN
The Moon and Saturn pass within 3°54' of each other in Capricornus

© ESA/Hubble & NASA

1 JUL
Globular cluster Messier 22 is well placed for observation in Sagittarius at +5.1

1 JUL
Open cluster IC 4756 is well placed for observation in Serpens at magnitude +5.0

9 JUL
Mercury reaches half phase, shining brightly at magnitude -0.2 in the morning sky

10 JUL
Comet C/2020 T2 (Palomar) makes its closest approach to the Sun at +9.9

12 JUL
Conjunction between the Moon and Venus in Leo

JARGON BUSTER

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

18 JUN

Open cluster NGC 6530 is well placed for observation in Sagittarius at +4.6

20 JUN

Jupiter enters retrograde motion, dazzling at magnitude -2.6 in Aquarius

20 JUN

Neptune enters retrograde motion, glowing at magnitude +7.9 in Aquarius

28 JUN

Conjunction between the Moon and Jupiter in Aquarius

28 JUN

The Moon and Jupiter pass within 4°10' of each other in Aquarius

28 JUN

Open cluster NGC 6633 is well placed for observation in Ophiuchus at +4.6

5 JUL

Mercury is at its greatest elongation west, dazzling at +0.3 in the dawn sky

7 JUL

15P/Finlay reaches its maximum brightness, glowing at a predicted +8.4 in Pisces

Source: Wikipedia commons © Roberto Mura

13 JUL

Mercury reaches its highest altitude, shining brightly at +0.3 in the morning sky

14 JUL

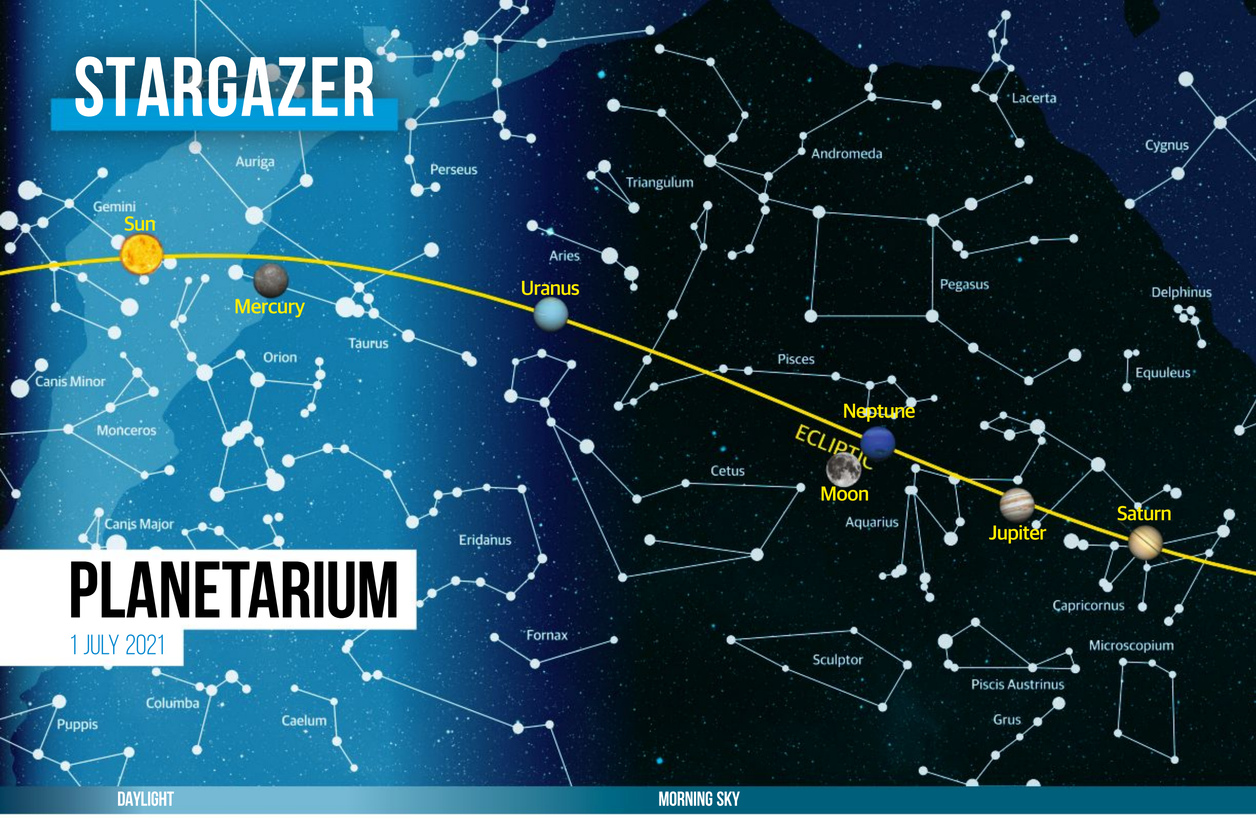
15P/Finlay makes its closest approach to the Sun at a predicted +8.4 in Taurus

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

STARGAZER

PLANETARIUM

1 JULY 2021



MOON CALENDAR

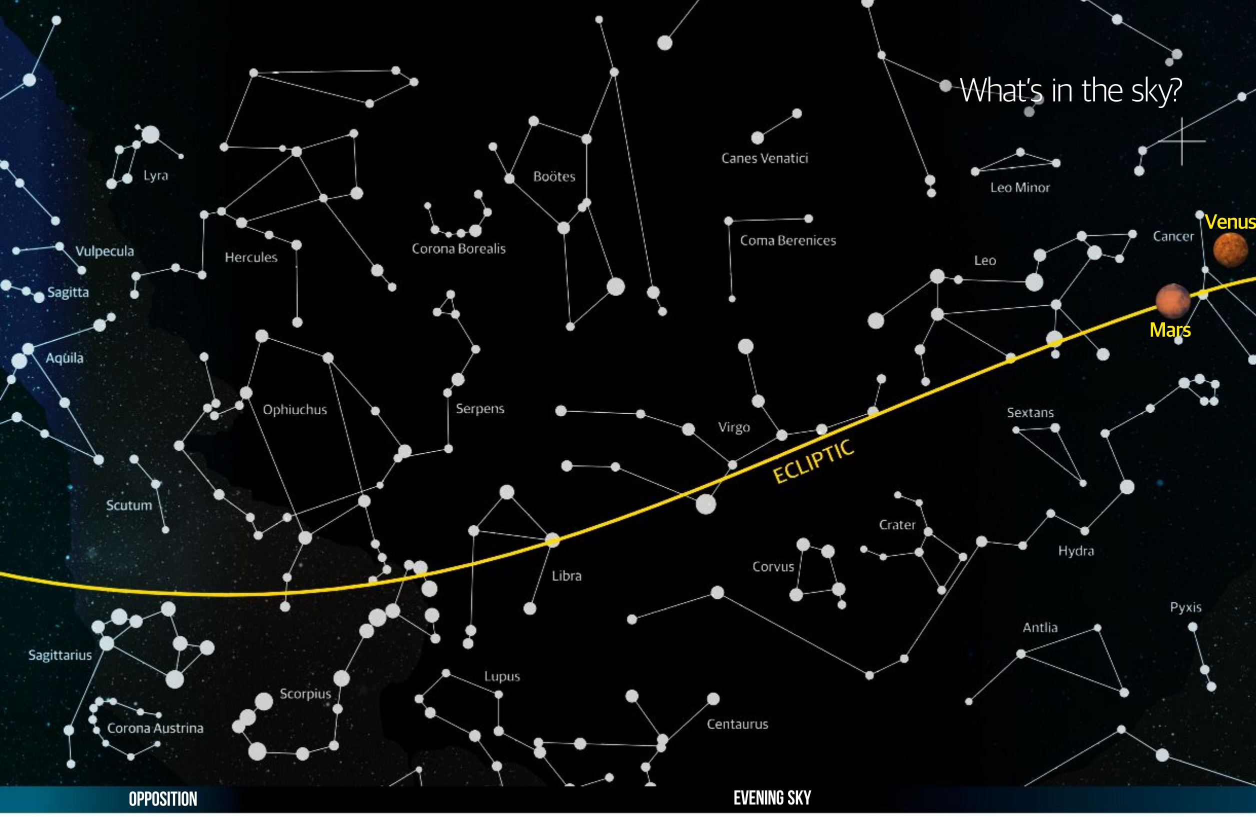
* The Moon does not pass the meridian on 23 June

17 JUN		45.5%	▼01:20 ▲11:50
18 JUN	FQ	57.0%	▼01:37 ▲13:09
19 JUN		68.3%	▼01:53 ▲14:30
20 JUN		79.0%	▼02:10 ▲15:54
21 JUN		88.1%	▼02:28 ▲17:21
22 JUN		95.0%	▼02:51 ▲18:51
23 JUN		--:--%*	▼03:21 ▲20:19
24 JUN	FM	99.0%	▼04:01 ▲21:37
25 JUN		99.9%	▼04:57 ▲22:39
26 JUN		97.6%	▼06:07 ▲23:24
27 JUN		92.5%	▼07:27 ▲23:56
28 JUN		85.2%	▼08:49 ▲--:--
29 JUN		76.4%	▲00:20 ▼10:08
30 JUN		66.7%	▲00:38 ▼11:24
1 JUL	TQ	56.5%	▲00:53 ▼12:36
2 JUL		46.4%	▲01:07 ▼13:46
3 JUL		36.6%	▲01:21 ▼14:55
4 JUL		27.5%	▲01:35 ▼16:04
5 JUL		19.2%	▲01:52 ▼17:13
6 JUL		12.2%	▲02:12 ▼18:22
7 JUL		6.5%	▲02:37 ▼19:29
8 JUL		2.5%	▲03:10 ▼20:31
9 JUL		0.4%	▲03:53 ▼21:23
10 JUL	NM	0.3%	▲04:48 ▼22:06
11 JUL		2.4%	▲05:53 ▼22:40
12 JUL		6.7%	▲07:05 ▼23:06
13 JUL		13.1%	▲08:22 ▼23:26
14 JUL		21.4%	▲09:39 ▼23:44
15 JUL		31.3%	▲10:57 ▼--:--

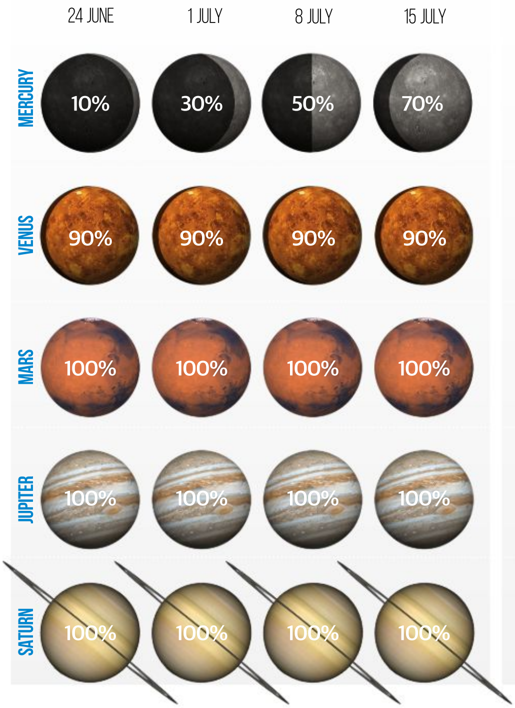
% Illumination
▲ Moonrise time
▼ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

What's in the sky?



ILLUMINATION PERCENTAGE



PLANET POSITIONS

All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
17 JUN	05h 05m 30s	+18° 37' 41"	Taurus	+4.1	04:41	20:33
24 JUN	05h 00m 37s	+18° 16' 31"	Taurus	+2.1	04:14	19:46
1 JUL	05h 10m 57s	+19° 12' 43"	Taurus	+0.8	03:48	19:33
8 JUL	05h 37m 24s	+20° 53' 11"	Taurus	+0.0	03:37	19:45
15 JUL	06h 19m 28s	+22° 26' 24"	Gemini	-0.7	03:38	20:08
17 JUN	07h 15m 53s	+23° 41' 14"	Gemini	-3.9	06:18	23:06
24 JUN	07h 52m 31s	+22° 28' 53"	Gemini	-3.9	06:36	23:07
1 JUL	08h 28m 17s	+20° 45' 23"	Cancer	-3.9	06:56	23:02
8 JUL	09h 03m 02s	+18° 33' 58"	Cancer	-3.9	07:16	22:53
15 JUL	09h 36m 43s	+15° 58' 19"	Leo	-3.9	07:40	22:44
17 JUN	08h 22m 40s	+20° 44' 21"	Cancer	+ 1.8	07:45	23:51
24 JUN	08h 40m 30s	+19° 39' 18"	Cancer	+ 1.8	07:44	23:35
1 JUL	08h 58m 08s	+18° 27' 57"	Cancer	+ 1.8	07:39	23:14
8 JUL	09h 15m 33s	+17° 10' 40"	Cancer	+ 1.8	07:38	22:57
15 JUL	09h 32m 48s	+15° 47' 55"	Cancer	+ 1.8	07:37	22:39
17 JUN	22h 16m 51s	-11° 41' 30"	Aquarius	-2.6	00:28	10:35
24 JUN	22h 16m 54s	-11° 43' 16"	Aquarius	-2.6	00:15	10:18
1 JUL	22h 16m 22s	-11° 48' 23"	Aquarius	-2.7	23:47	09:48
8 JUL	22h 15m 14s	-11° 56' 46"	Aquarius	-2.7	23:17	09:17
15 JUL	22h 13m 32s	-12° 08' 13"	Aquarius	-2.8	22:51	08:49
17 JUN	21h 01m 38s	-17° 38' 44"	Capricornus	+0.5	00:04	08:56
24 JUN	21h 00m 27s	-17° 44' 43"	Capricornus	+0.4	23:34	08:25
1 JUL	20h 59m 01s	-17° 51' 41"	Capricornus	+0.4	23:04	07:54
8 JUL	20h 57m 21s	-17° 59' 28"	Capricornus	+0.3	22:37	07:26
15 JUL	20h 55m 31s	-18° 07' 53"	Capricornus	+0.3	22:10	06:57

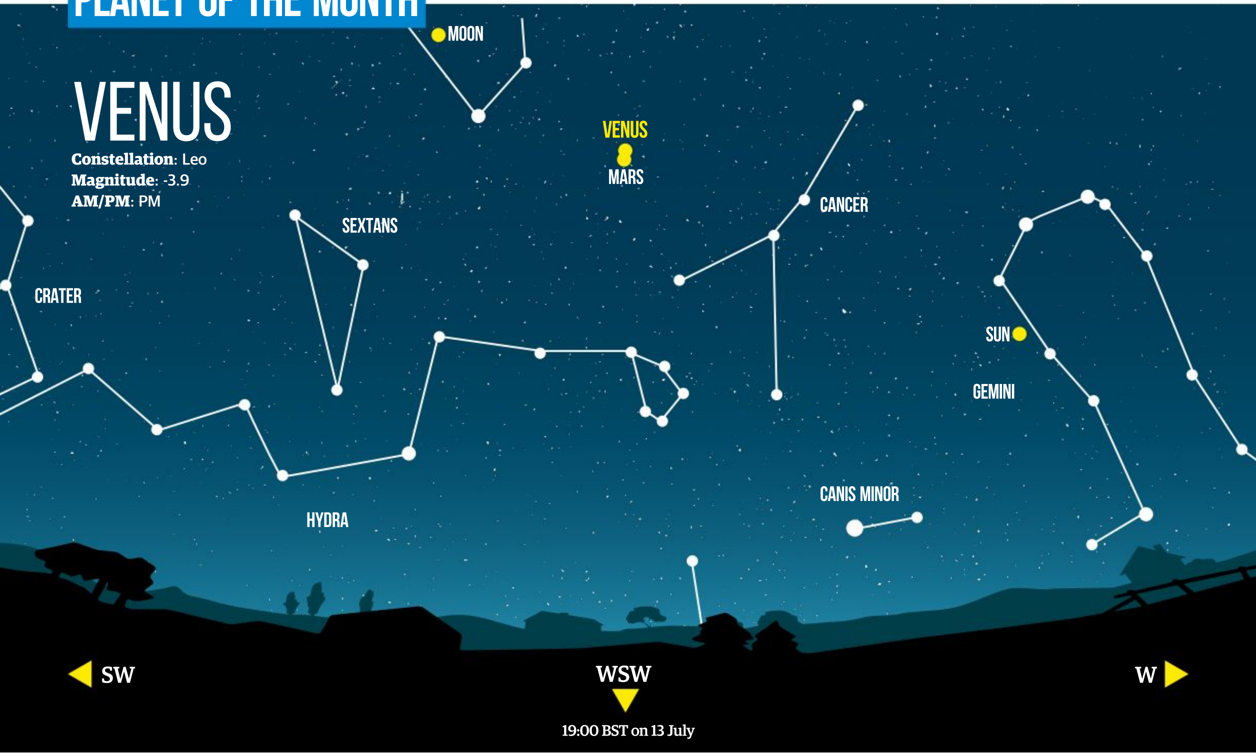
THIS MONTH'S PLANETS

Venus takes pride of place as an evening star, dazzling at an impressive magnitude for naked eye, binocular and telescope observers

PLANET OF THE MONTH

VENUS

Constellation: Leo
Magnitude: -3.9
AM/PM: PM



19:00 BST on 13 July

Venus is our Planet of the Month, not just because it's bright and easy to find in the sky, but because there will be a lot going on around it in the sky too. Venus is often called 'Earth's Twin', but that's very misleading because the only thing they have in common is their size – they are roughly the same diameter. While Earth is a lush paradise, teeming with life, Venus is a hellish planet with a poisonous atmosphere, crushing surface pressure and lethal surface temperatures.

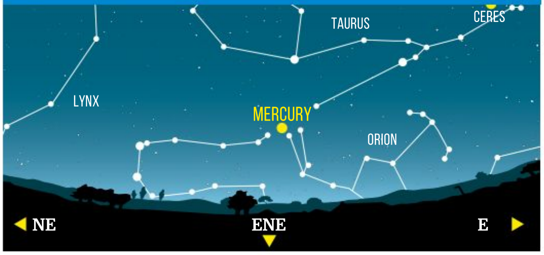
Because Venus orbits the Sun so closely it can never appear very far from it in the sky. Unlike the planets Mars, Jupiter and Saturn, which all orbit much farther from the Sun than Venus – and indeed than Earth – we can never see Venus high in a dark sky, only as a spark of light low in the sky in the morning or evening twilight, depending on the time of year. When it's visible before sunrise Venus is known as the 'morning star', but this month Venus is an 'evening star', clearly visible to the naked eye as a bright point of light low in the southwest after sunset, looking like a metallic spark in the twilight.

Look more closely as the sky begins to darken and you'll see Venus has company in the twilight – a fainter, more orange-hued star will be shining to its upper left. This is actually Mars, but the Red Planet is definitely upstaged by Venus this month. As June moves into July the two planets will appear to drift closer and closer together in the sky, until they are almost touching on the evening of 13 July.

On that evening the two planets will be just the width of the full Moon apart, and will be a lovely sight through a pair of binoculars. They'll make a great photographic target too, and you might even capture them with the camera on your phone if you hold it steady and zoom in on them.

There is growing demand for more robotic missions to Venus, so in the years to come we might see camera-covered balloons drifting through its atmosphere, or even armoured rovers trundling across its rocky, baked surface. In the meantime enjoy looking at Venus shining in the twilight as the evening star.

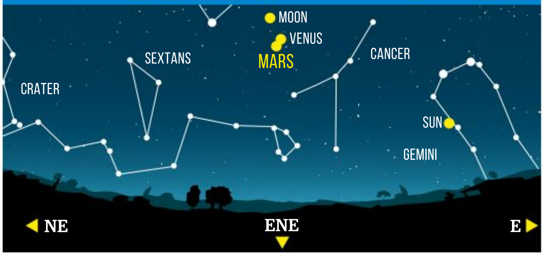
MERCURY 05:00 BST on 13 July



Constellation: Taurus **Magnitude:** +0.0 **AM/PM:** AM

At the start of our observing period Mercury is too close to the Sun to be seen, but as the days pass it will slowly pull away and climb up into the predawn sky to appear as a copper-hued star very low in the northeast. All through June it will remain so low and so close to the Sun that it will be a challenge to see, and won't be more easily visible until the start of July.

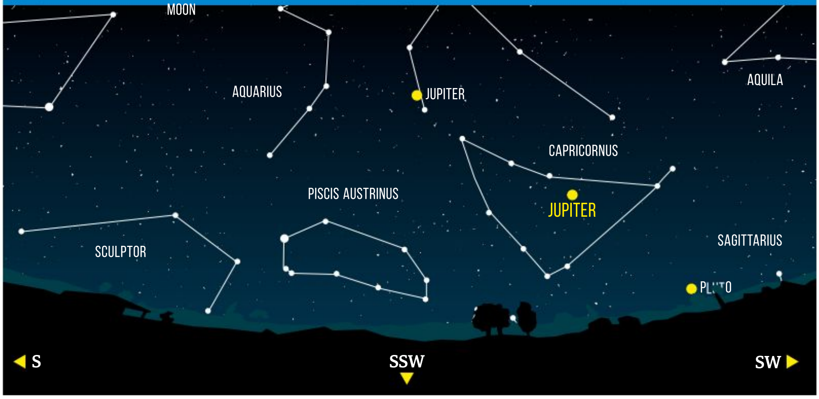
MARS 20:00 BST on 12 July



Constellation: Cancer **Magnitude:** +1.8 **AM/PM:** PM

Mars will be an evening object this month, visible low in the west as the sky begins to darken. At magnitude +1.8 Mars will be easily visible to the naked eye, but will be overshadowed by much brighter Venus, which will be shining to its lower right. As the evenings pass Mars will appear to move towards Venus and the Sun, shining a little lower in the sky each evening.

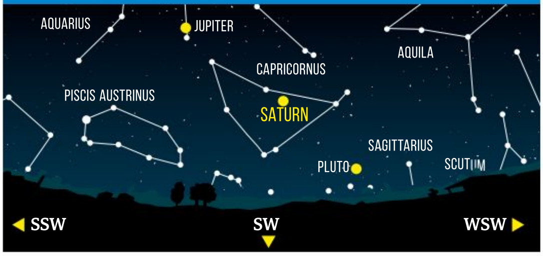
JUPITER 04:00 BST on 28 July



Constellation: Aquarius
Magnitude: -2.5
AM/PM: AM

At the start of our observing period Jupiter, the largest of all the planets in our Solar System, will be a morning object, visible to the naked eye as a bright blue-white star low in the southeast before sunrise, just a short distance to the left of fainter and more golden-hued Saturn. However, by the middle of July Jupiter will be rising before midnight, so could be considered an evening object. At the end of June Jupiter will be joined in the predawn sky by the waning gibbous Moon. On the 28th the Moon will be shining to Jupiter's lower right.

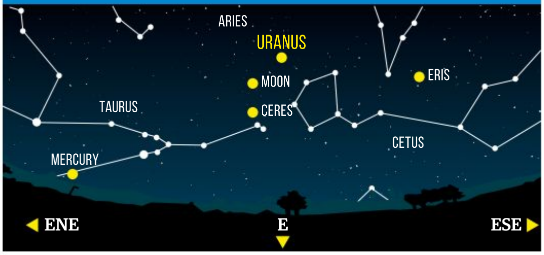
SATURN 04:00 BST on 28 July



Constellation: Capricornus **Magnitude:** +0.4 **AM/PM:** AM

At the start of our observing period Saturn, the famous Ringed Planet, will be visible low in the southeast before sunrise, a gold-hued 'star' a short distance to the right of brighter and bluer Jupiter. By the middle of July Saturn will be rising well before midnight, visible all through the warm, light nights of summer but never climbing very high above the horizon.

URANUS 04:00 BST on 5 July



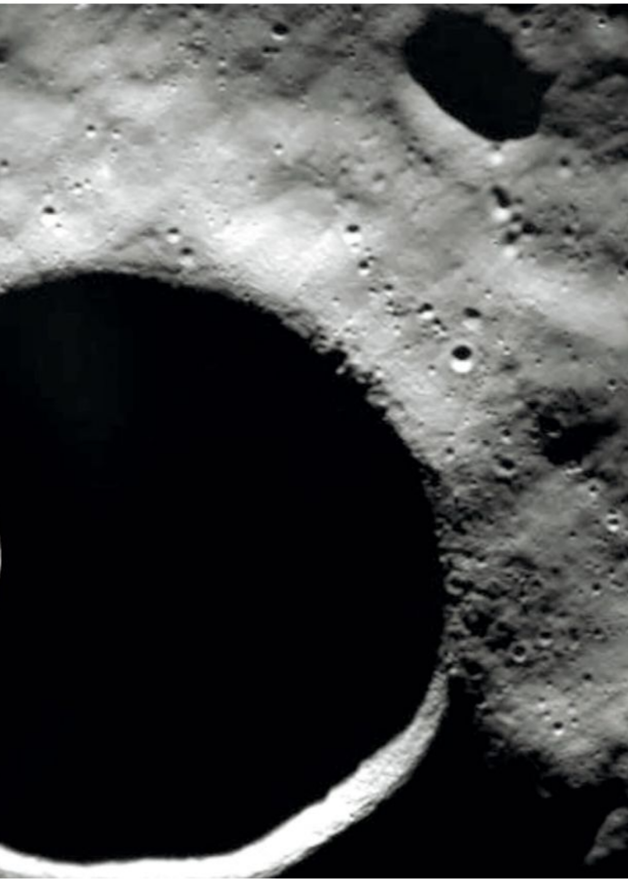
Constellation: Aries **Magnitude:** +5.9 **AM/PM:** AM

Uranus is a morning object through June and into July, a little higher in the sky and further away from the Sun each morning. At magnitude +5.9 Uranus would be a naked-eye object for many under a dark sky, but with the sky in June and July never growing truly dark, it's likely Uranus' faint light will be overwhelmed, and you'll need a pair of binoculars to find it.

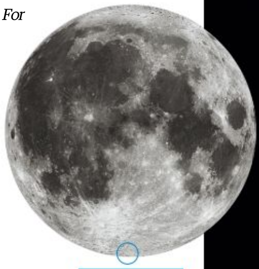
MOON TOUR

SHACKLETON CRATER

Take an imaginary trip to the site of the first lunar base – in both fact and fiction



© ESA



One popular sci-fi TV series at the moment is *For All Mankind*, which chronicles a fascinating and thrilling alternative history of the US space program. We all know that in real life Neil Armstrong and Buzz Aldrin were the first astronauts on the Moon, landing their Apollo 11 Lunar Module 'Eagle' in the Sea of Tranquillity. The rest, as they say, is history.

In the alternate history of *For All Mankind*, the Soviets beat the US to the Moon – Alexei Leonov takes that first small step instead of Armstrong, quickly followed by a female cosmonaut, and it all follows on from there as the Space Race goes into top gear. By the mid-1970s there have been 25 Apollo missions, carrying both male and female crews, and both superpowers have small military outposts on the Moon, built on the rim of a crater down at the Moon's south pole called Shackleton. Why there? Because its shadowy depths, never illuminated by the Sun, contain priceless deposits of ice that can be processed to make fuel and water, allowing lunar settlers to 'live off the land' instead of lugging those resources up from Earth.

TOP TIP!

Look on NASA websites for images of Shackleton crater taken from orbit.

Shackleton is shown so realistically in the series that many fans of the show have apparently been asking astronomers if they could show them 'the crater from the TV series' with their telescopes. Unfortunately, that's not possible, because being at the lunar south pole, Shackleton is only ever seen edge-on from Earth and is never illuminated by the Sun, which is exactly why it was chosen as the site of the superpowers' bases in the TV series, and also why NASA is planning to establish a real, permanent base there by 2028 after the initial crewed Artemis missions have surveyed the area.

Real life will mirror fiction in this way – just like in the TV series, orbital surveys of Shackleton have detected traces of water within the crater, perhaps ice deposited there by comets. But unlike the glittering veins and chunks of pure ice shown being hacked out of the crater walls by *For All Mankind*'s axe-wielding astronauts, in real life the water found in the crater is all mixed in with the rocks and dust, so it will require a lot of processing to access. That's just chemistry and engineering though, two things NASA is great at.

Appropriately named after the famous south polar explorer Ernest Shackleton, the crater itself is quite small. In fact, if it were anywhere else on the Moon it would be quite unremarkable. Only 12 kilometres (7.4 miles) across and just over four kilometres (2.4 miles) deep, it's only interesting because of a useful combination of the water deposits detected within it and the height of several of the tallest peaks along its rim. Nicknamed the 'Peaks of Eternal Sunlight', these lofty summits are bathed in almost permanent sunlight, which means a base built on Shackleton's rim could be powered by solar panels on the peaks, with its explorers and scientists sustained by water mined from within the crater.

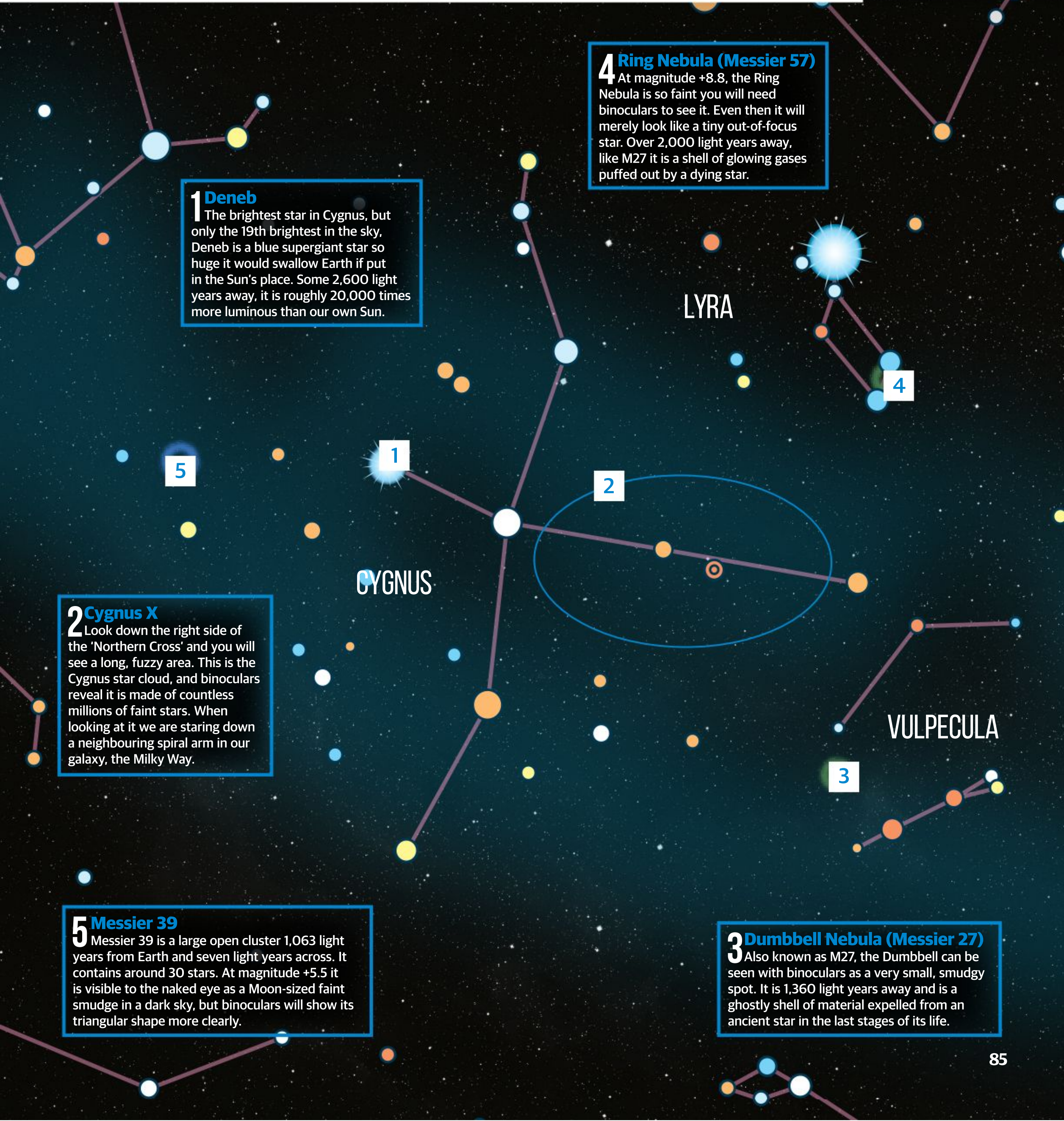
It's a little unfortunate that we can't see Shackleton properly from Earth, because in the years to come it's going to become a very important and busy place, a lunar beachhead in the human exploration of the Solar System from where we will strike out to the asteroids and Mars.

As NASA gears up towards its return to the Moon in 2024, Shackleton will become the target for many robotic missions, perhaps including rovers, so even though you won't be able to see it directly through your binoculars or telescope, it's good to know where Shackleton is. On a clear night when the Moon is high and bright in the sky, you should cast your eyes down towards the south pole of the Moon and imagine what future astronauts will see and do there, more than half a century after their fictional counterparts explored it on TV.

If you're one of our many younger readers you might bounce around the rim of Shackleton crater yourself one day, or gaze down into its depths from one of the Peaks of Eternal Light, looking down to where your colleagues are mining water – not just for you, but for all humankind.

NAKED EYE & BINOCULAR TARGETS

The summer night sky is bright, but if it's clear you can still see shells of gas billowing away from dying suns and a glittering cloud of stars



1 Deneb
The brightest star in Cygnus, but only the 19th brightest in the sky, Deneb is a blue supergiant star so huge it would swallow Earth if put in the Sun's place. Some 2,600 light years away, it is roughly 20,000 times more luminous than our own Sun.

2 Cygnus X
Look down the right side of the 'Northern Cross' and you will see a long, fuzzy area. This is the Cygnus star cloud, and binoculars reveal it is made of countless millions of faint stars. When looking at it we are staring down a neighbouring spiral arm in our galaxy, the Milky Way.

3 Dumbbell Nebula (Messier 27)
Also known as M27, the Dumbbell can be seen with binoculars as a very small, smudgy spot. It is 1,360 light years away and is a ghostly shell of material expelled from an ancient star in the last stages of its life.

4 Ring Nebula (Messier 57)
At magnitude +8.8, the Ring Nebula is so faint you will need binoculars to see it. Even then it will merely look like a tiny out-of-focus star. Over 2,000 light years away, like M27 it is a shell of glowing gases puffed out by a dying star.

5 Messier 39
Messier 39 is a large open cluster 1,063 light years from Earth and seven light years across. It contains around 30 stars. At magnitude +5.5 it is visible to the naked eye as a Moon-sized faint smudge in a dark sky, but binoculars will show its triangular shape more clearly.

Part of the Veil Nebula, next to the Witches Broom

© Getty

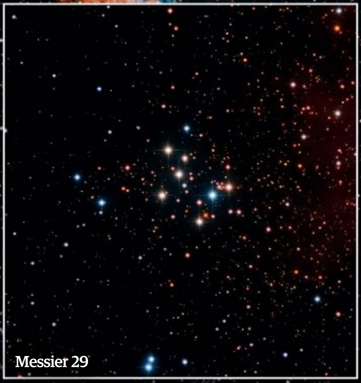
DEEP SKY CHALLENGE

SUMMER'S DAZZLING DEEP-SKY TREATS

On light summer nights, glittering star clusters, a dead star and a beautiful double star await

Usually we like to set you difficult observing challenges – faint star clusters, or nebulae so misty they're almost not there – but as it's summer and the sky never gets dark enough to see the really faint fuzzies, this month's challenges aren't so tough. However, providing the northern sky isn't painted with a dramatic display of bright-blue and silver noctilucent clouds, if you stay up late the sky does get just dark enough to let you see some lovely sights through a telescope, and in the hours after midnight a telescope will give you very pleasing views of some beautiful objects.

Although the broad, frothy band of the Milky Way dominates the early summer sky – running right through Cygnus (the Swan) and cutting it and the whole sky in half – embedded in the Milky Way you will find the ghostly, rippled remains of dead stars and much more, and even a small telescope will give you a beautiful view of one of the loveliest and most popular double stars in the whole sky at the base of the Northern Cross. Don't believe those who insist that the summer sky is a write-off. As long as you don't mind a late night and bleary eyes the next morning, there's still lots to see.

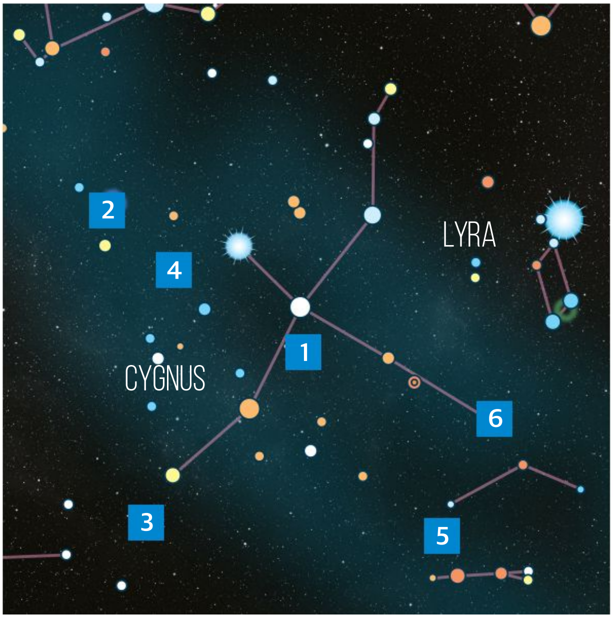


Messier 29

Source: Wikipedia Commons © Veryoldphotons

© Getty

North America Nebula (NGC 7000)



1 Messier 29

This little-known magnitude +6.6 open cluster contains only a few scattered stars, forming the shape of an open box or chest. Small to medium telescopes pick it out nicely from the background sky.

3 Veil Nebula

The ghostly remains of a star that blew up between 5,000 and 8,000 years ago, the seventh-magnitude Veil Nebula consists of two arcs of faint gas. A medium-aperture telescope is definitely needed to show structure and hints of colour.

5 Dumbbell Nebula (Messier 27)

While the famous Dumbbell Nebula is just a small smudge in small telescopes, medium and large-aperture instruments will show its twin lobes of blue-green gas – and on still nights the +13.5 star at its centre too.

2 Messier 39

This loose open cluster, roughly triangular in shape, covers roughly the same angular diameter in the sky as the Moon. It is best seen through small telescopes using low magnifications.

4 North America Nebula (NGC 7000)

Although this emission nebula covers as much sky as around four full Moons and can be seen in binoculars, a large telescope is needed to pick out its distinctive shape. Lower magnifications work best on light summer nights.

6 Albireo (Beta Cygni)

One of the most beautiful double stars, Albireo can be split into a third-magnitude gold star and a +4.7 sapphire-hued star, 20 inches apart, by even small telescopes. But larger scopes will also split the brighter star in the pair into two stars.

THE NORTHERN HEMISPHERE

Many nebulae are visible, and the central part of our galaxy is teeming with star clusters to enjoy

Fully in the midst of summer, the shorter, warmer nights offer a splendid selection of nebulae, star clusters and bright stars to observe. Red supergiant Arcturus proudly makes its appearance known in the constellation of Boötes, while the unmistakable Summer Triangle is easily observed this month, with the stars Altair, Deneb and Vega – in the constellations of Aquila, Cygnus and Lyra respectively – marking each of its vertices.

Summer is an ideal time to see the Milky Way, with Sagittarius and Scorpius marking its centre – here you'll be able to see a selection of clusters, including the Ptolemy Cluster, also known as Messier 7.

USING THE SKY CHART

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

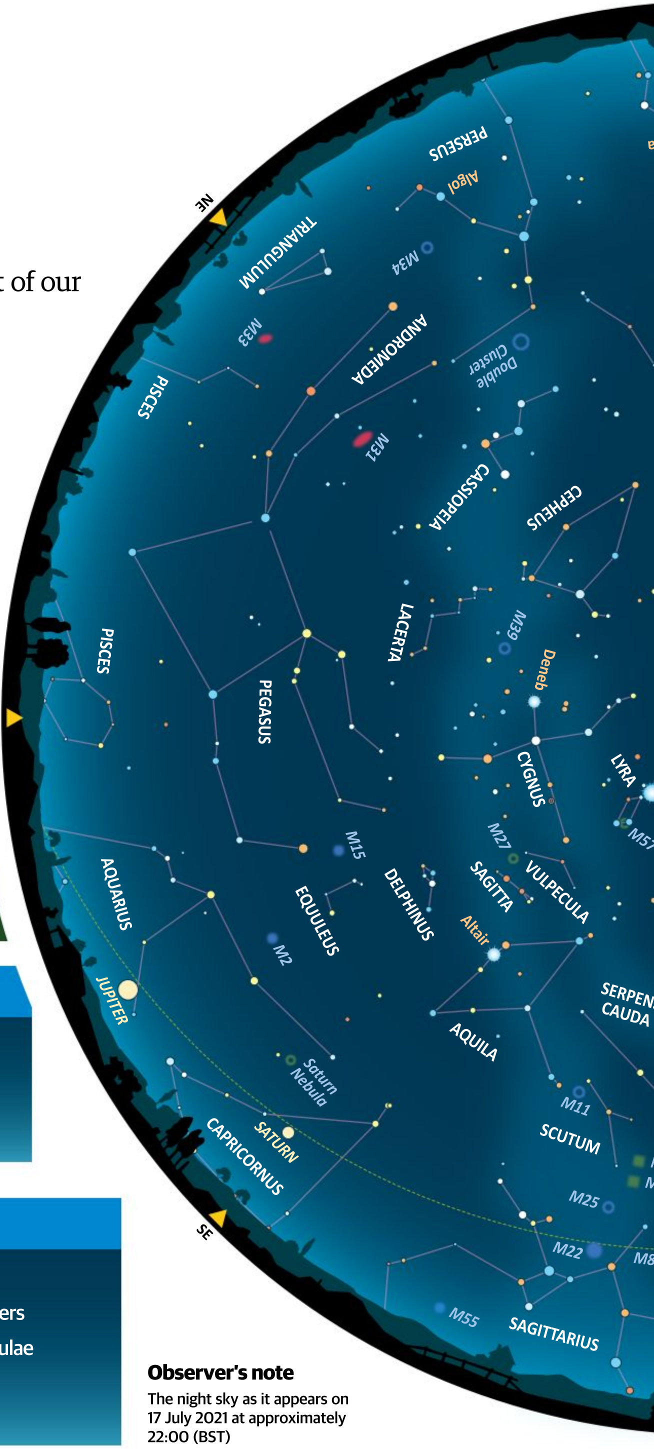
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- ● 1.5 to 2.0
- ● 2.0 to 2.5
- ● 2.5 to 3.0
- ● 3.0 to 3.5
- ● 3.5 to 4.0
- ● 4.0 to 4.5
- ● Fainter
- ⊙ Variable star

SPECTRAL TYPES

- ● O-B
- ● A
- ● F
- ● G
- ● K
- ● M

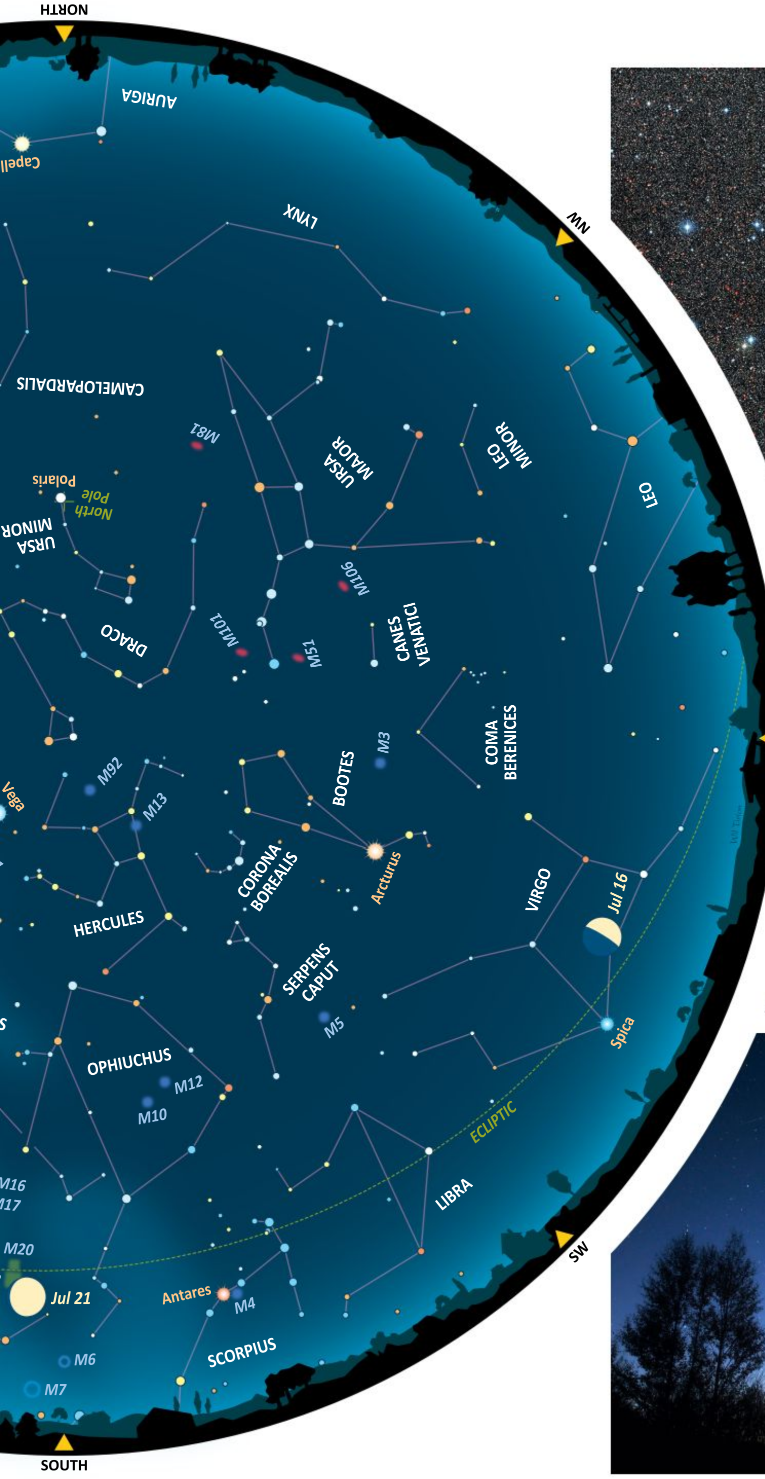
DEEP-SKY OBJECTS

- ○ Open star clusters
- ● Globular star clusters
- ■ Bright diffuse nebulae
- ○ Planetary nebulae
- ⬬ Galaxies



Observer's note

The night sky as it appears on 17 July 2021 at approximately 22:00 (BST)



Ptolemy's Cluster (Messier 7)

© ESO

Stars of the Summer Triangle

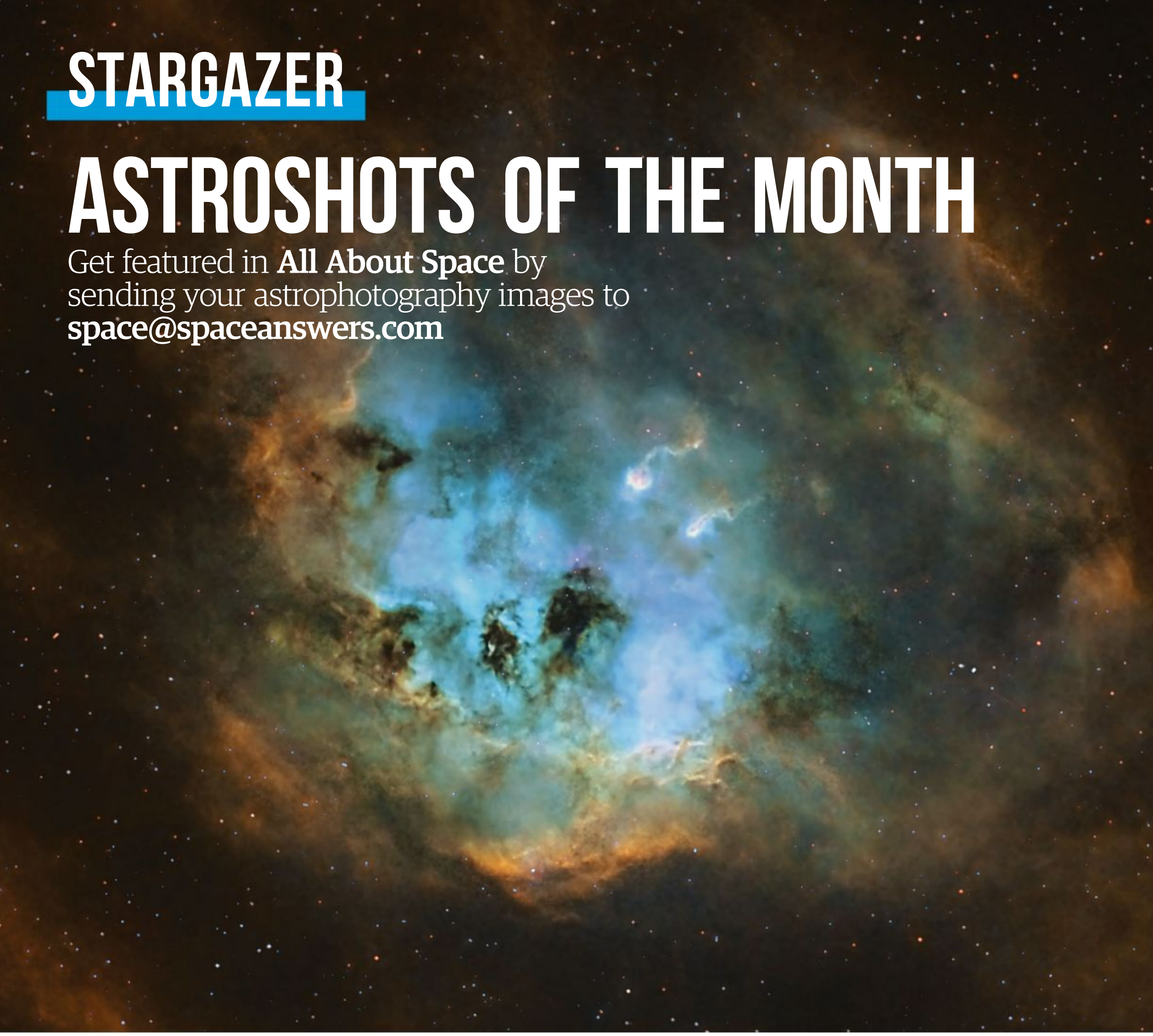
© Getty

Arcturus (Alpha Boötis)

© Getty

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**



Chris Grimmer

Location: Norwich, UK

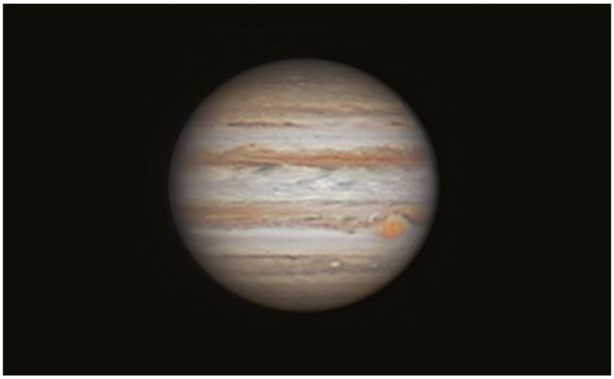
Telescope: Celestron C9.25 Schmidt-Cassegrain and William Optics GT-81 refractor

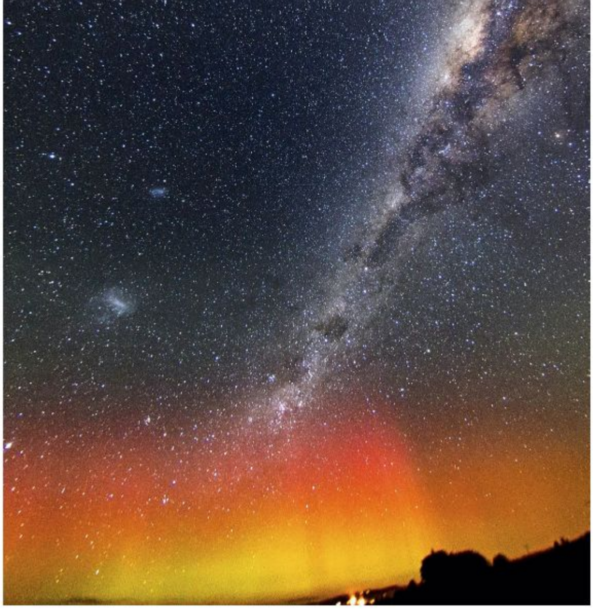
"My route into astrophotography started a couple of years back when one night in my local pub, I discovered that the pub landlord's son owned a telescope. In the early hours of the morning, we headed outside to the car park to observe the night sky. I soon paid a visit to my local astronomical society, and the following day bought my first scope. I have always been interested in photography, so it wasn't long before I had modified a cheap webcam and got my first picture of Jupiter.

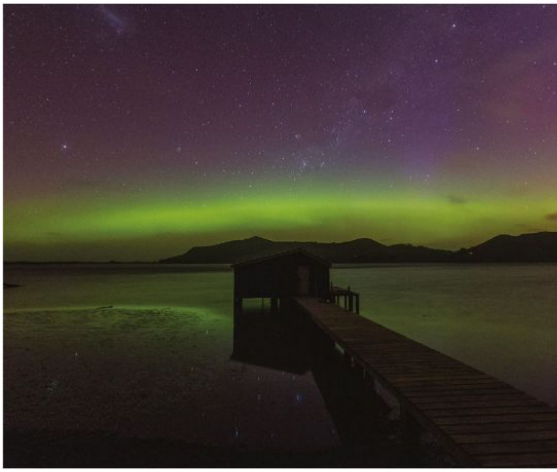
"It was then that the astronomy bug really hit. From that point on my kit became rapidly upgraded, to the point where not a month passed without something new being delivered to me."

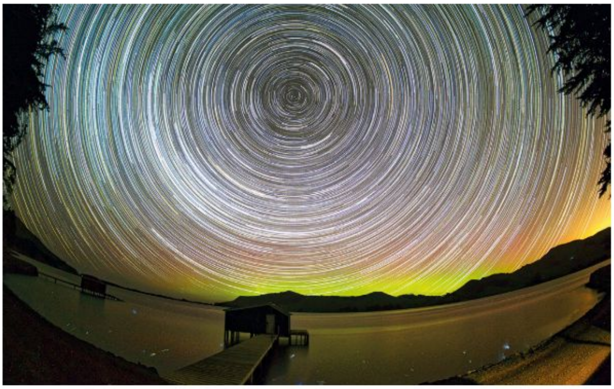
Above: Tadpoles Nebula (IC 410)

Right: Jupiter's swirling storms and atmospheric bands









Ian Griffin

Location: Dunedin, New Zealand

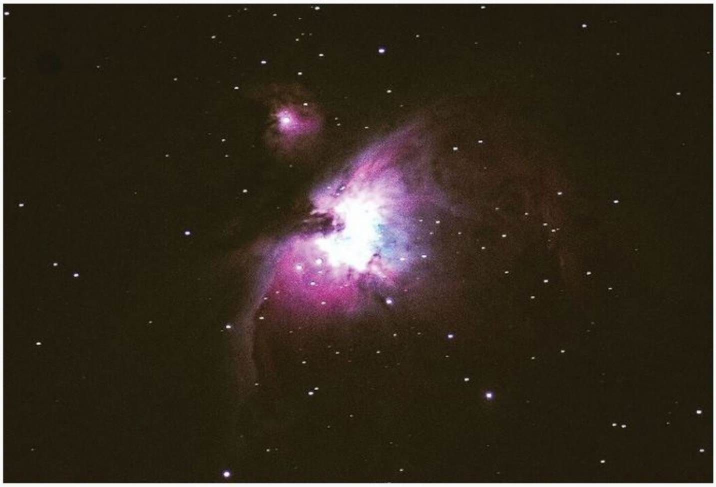
Telescope: N/A

"Just over three years ago, a new job meant that I moved from Oxford in the UK to Dunedin on the South Island of New Zealand. Since moving here I've developed a passion for astrophotography, both with and without a telescope. The Southern Hemisphere sky is teeming with fascinating objects, and it's a real pleasure to live in a part of the world where the centre of the galaxy passes overhead in winter. Here in Dunedin we also get frequent displays of the aurora australis, which can look truly spectacular against the backdrop of the beautiful New Zealand landscape."

Above: Dusty path of the Milky Way

Above (right): The southern lights, aurora australis

Right: Star trails in New Zealand



Left: Orion Nebula (Messier 42)

Michael Saltsman

Location:
Greater Manchester, UK

Telescope:
Celestron NexStar 127SLT

"I am an estate agent by day and an astrophotographer by night. I studied photography at school, but also loved physics – I was even at school with Brian Cox.

"I have always loved taking photographs of the sky, and I own a computerised scope to observe the planets and deep-sky objects. One of my great passions is to share my wide-field Milky Way shots on social media, where large corporations have shared my work. My aim is to image the galaxy from the Atacama Desert in Chile one day."

REVIEW

CELESTRON NEXSTAR EVOLUTION 8

This computerised Schmidt-Cassegrain offers an optical system that ranks as one of the best we've ever had the pleasure of looking through

Reviewed by Gemma Lavender

TELESCOPE ADVICE

Cost: £1,999 (approx. $2,837)

From: Wex Photo Video

Type: Schmidt-Cassegrain

Aperture: 8"

Focal length: 80"

Celestron's telescopes continue to evolve and improve, and it's done an amazing job of merging its highly regarded Schmidt-Cassegrain telescopes with a computerised, single-fork mount for an easier and much more enjoyable experience when observing the night sky: meet the NexStar Evolution range.

The NexStar Evolution range has quite a moderate price tag, but according to Celestron it has everything an intermediate astronomer needs when navigating the celestial landscape to track down and gaze upon some tantalising views, whether it's magnifying the spiral arms of the Pinwheel Galaxy (Messier 101) in Ursa Major (the Great Bear) or staying much closer to home to pick out the rings of gas giant Saturn. The telescope also provides a very good platform for astrophotography, no matter if it's basic or at a much more advanced level.

Of the Celestron NexStar Evolution range, we tested the Evolution 8. Included with the optical tube assembly (OTA) is a robust stainless-steel tripod, which supports the whole set-up with ease. The single-fork arm is the pride of the instrument; it can mechanically navigate the night sky with the touch of a button via two perpendicular movements thanks to an alt-azimuth mount, which is powered by a long-lasting, rechargeable lithium-ion battery. In our opinion the internal battery seems to be an underappreciated aspect – it saves having to spend extra money on a battery pack, and as an added bonus an international AC adapter is also provided. On a good run the battery allows ten hours of continuous observation.

Also built into the mount is the telescope's very own Wi-Fi network, allowing the user to connect and control the telescope via Celestron's SkyPortal, an app that can be downloaded for free on both iOS and Android devices. By making use of the most modern technologies available, navigating from planet to star to nebula can be achieved with ease with just the touch of a button.

The icing on the cake is the eight-inch Schmidt-Cassegrain telescope, with improved EdgeHD optics for crisper, clearer sights of any targets you wish to observe. There are also several important extras included in this package, most notably the latest StarSense technology, which features an attachable camera and hand control to deliver a painless AutoAlign process.

There is also a StarPointer Pro finderscope, which employs a red-dot technology with a surrounding ring that aids with pinpointing your desired object in the field of view with minimal fuss.

The NexStar Evolution 8 also comes with a 1.25-inch star diagonal and two 1.25-inch Plössl eyepieces at 12.5mm and 40mm, allowing magnifications of 156x and 51x respectively. Before we headed out for a night of observing, the first thing we noted was the telescope's weight, which totals 18.5 kilograms. The NexStar Evolution 8 will be tricky to transport for many, so it is important to take that into account before planning any sky-watching trips beyond your own backyard.

Right: The whole set-up is heavy, but is very well supported by the sturdy tripod

Below: The tube can be detached from the tripod for easy transport

BEST FOR...

- INTERMEDIATE
- HIGH BUDGETS
- PLANETARY VIEWING
- LUNAR VIEWING
- DEEP-SKY OBJECTS
- ASTROPHOTOGRAPHY

> “IT HAS EVERYTHING AN INTERMEDIATE ASTRONOMER NEEDS WHEN NAVIGATING THE CELESTIAL LANDSCAPE”

Upon arrival at our designated site for the night, the assembly of the telescope proved to be fairly straightforward – something that’s welcomed by any astronomer who just wants to get down to making observations straight away, without spending a great deal of time setting up. In less than 30 minutes the telescope was assembled, running and ready for alignment. We decided to utilise the StarSense AutoAlign camera, as it was a clear night at our location in a dark-sky reserve.

At the time of our test, using this technology was a new experience to us, but it was very straightforward and didn’t take longer than your average manual alignment. Be warned though – the technology will only work at its best under reasonably clear skies free of light pollution and with an array of stars at your disposal. Anything less and a message will pop up on the hand control that reads ‘too few stars’.

Once aligned, we couldn’t wait to test the NexStar Evolution 8’s mettle. Our iPhone 11 connected to the telescope with ease, and with the interactive interface also doubling as a planetarium app, choosing our targets was so simple. The first object on our checklist was the biggest, brightest and most obvious object visible to the naked eye: the Moon.

Our lunar companion was at waxing gibbous phase at the time of observation, with 85.9 per cent luminosity. With the 40mm eyepiece attached, the NexStar Evolution 8 offered a crisp, bright and visually stimulating sight, with the lunar surface fitting perfectly within the field of view. We recommend purchasing a Moon filter to pare down any dazzling brightness and to improve contrast for picking out detail.

Switching to the 12.5mm Plössl allowed us to take a closer look at the rugged lunar terrain. From the dark patches of the lunar mare to the distinguishable craters of Tycho and Copernicus and the lunar terminator, the optics presented a crisp view with high clarity and resolution.

Moving away from the Moon, we explored some deep-sky targets in Orion (the Hunter). Heading over to our winter favourite, we took the time to gaze upon stellar opposites Rigel and Betelgeuse. The redness of the latter was easily recognisable, and the optical system seemed to have no major issues with chromatic or spherical aberration. Slewing to the opposite corner of Orion, we easily picked out the bluish-white hue of Rigel.

Again there were no issues or interference with the resolution of this brilliant magnitude +0.12 supergiant. Continuing our tour of the constellation, we tested the optical system on the more diffuse Orion Nebula (Messier 42), which required reverting back to the 40mm eyepiece. Even with the star-forming region's large size, the Plössl could accommodate the majority of the nebula. The central concentration of light was a magnificent sight. Combined with the surrounding dust trails stopping the visible light in its path to Earth, there was an appreciated disparity.

As this mount is motorised - and therefore capable of tracking a celestial object as it moves across the sky - it's a must-try for some serious astrophotography. It's specified that the telescope can accommodate most cameras, especially larger format charge-coupled device (CCD) and DSLR cameras. However, if you're looking to improve your images, you should purchase the 'Wedge' for the NexStar Evolution, which enables long-exposure astrophotography.

The Celestron NexStar Evolution 8 is an extremely impressive piece of kit. It's easy to set up, and by taking advantage of all the latest technology, combined with its optical prowess, is capable of providing a complete high-definition tour of the night sky. With a price that's suited to large budgets, it's a sturdy and reliable instrument that comes with a 24-month warranty. It's a worthy investment for those who are veterans of viewing the night sky, but not so much for those who are just dipping their toe into sky-watching. For beginners and casual astronomers, we'd recommend the NexStar or Astro-Fi range of Celestron telescopes.

The NexStar Evolution 8's optical system ranks as one of the best we've ever had the pleasure of looking at the universe through. Operation of its WiFi technology is seamless, while the computerised GoTo mount boasts exceedingly high performance. The NexStar Evolution 8 can be pushed to its useful magnification of 480x without suffering the consequences of poor, blurry images.

FOR

- ⊕ No visual defects such as colour fringing, warping or coma
- ⊕ Excellent views of both deep-sky and Solar System targets
- ⊕ Easy to set up and align
- ⊕ Good amount of accessories supplied

AGAINST

- ⊖ Set-up isn't very portable
- ⊖ Not suitable for beginners
- ⊖ Big investment

Right: With built-in WiFi, you can connect your phone and easily slew to targets with it

Below: The tripod features an accessory tray - handy for keeping eyepieces in order

3 FREE DIGITAL BOOKS
FOR EVERY READER!

WORTH £30

DISCOVER AMAZING FACTS AND MINDBLOWING THEORIES IN UNDER A MINUTE
NEW
60 SECOND SCIENCE
IN ASSOCIATION WITH HOW IT WORKS
Includes 18 exciting experiments to try at home
Amazing illustrations and diagrams
NEW
HOW IT WORKS BOOK OF
SPACE
Everything you want to know about the universe we live in
OVER 1000 AMAZING FACTS
Digital Edition
SOLAR SYSTEM
EXPLORATION
UNIVERSE
ASTRONOMY
LIVE SUSTAINABLY
NEW
Save THE World
WHAT CAN YOU DO TO FIGHT THE CLIMATE CRISIS?
AN INTERACTIVE JOURNAL

60 SECOND SCIENCE

Welcome to **60 Second Science**. This fact-packed guide introduces fundamental principles in physics, biology and chemistry with clear, concise explanations, infographics and illustrations. From the Big Bang to quantum mechanics and from fossils to Wi-Fi, you'll be up to speed with the latest breakthroughs in no time. Throughout the book you'll also have the opportunity to put these theories into practice with some easy-to-follow experiments. See how circuits work with batteries made from lemons, detect Earth's magnetic field by making your own compass, learn how to instantly freeze water with a single touch and much more.

BOOK OF SPACE

Space has fascinated humankind from the earliest days of civilisation, and as we keep scratching the surface of the vast universe in which we live, our sense of awe and wonder continues to grow unabated. With the technological advancements being made by the world's space agencies, we understand more than ever the things that are happening beyond our own planet. This new edition of the **How It Works Book of Space** has been updated with more of the latest astronomical advancements, stunning space photography from the most advanced telescopes on the planet and glimpses at what the future of space exploration holds.

SAVE THE WORLD

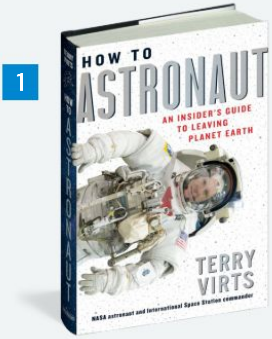
We're on the precipice of destroying our home planet forever, and action needs to be taken to save it - even on a small scale. Use the information in this interactive journal to identify areas in your life where you can make more eco-friendly choices, and track your habits with our interactive spreads. It's a statistical miracle that Earth has maintained its habitability in order to accommodate life for billions of years, so it's worth seeing what you can do to keep the planet this way for a while longer. Throughout the book you'll also notice 11 'myths' - these pages bust common misconceptions about climate change and reveal the truth behind these lies.

DOWNLOAD YOURS NOW AT: SURVEYMONKEY.CO.UK/R/TMP2KVL

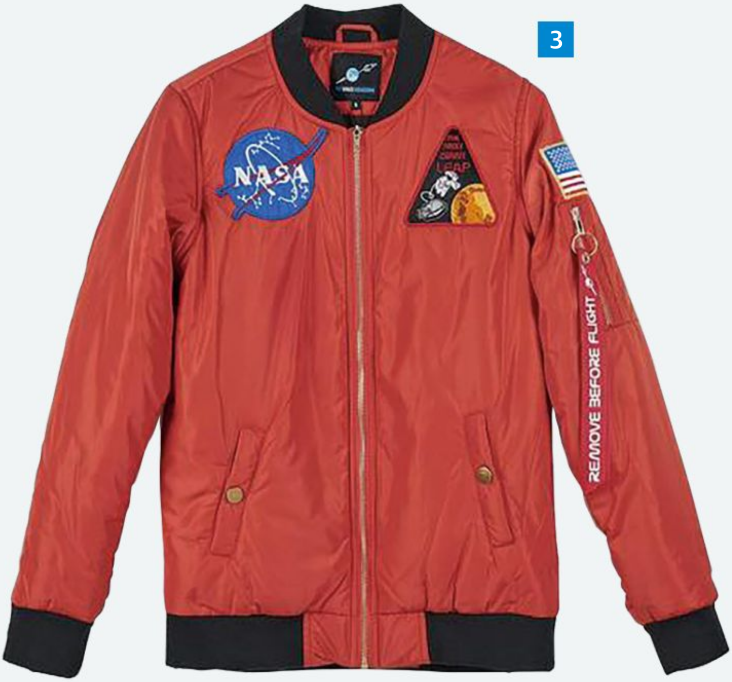
IN THE SHOPS

The latest books, apps, software, tech and accessories for space and astronomy fans alike

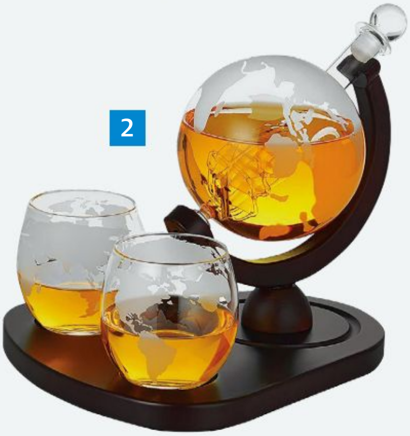
1



3



2



FOR READERS

HOW TO ASTRONAUT: AN INSIDER'S GUIDE TO LEAVING PLANET EARTH

Cost: £21.99 / $27.95

From: Waterstones

1 Embark on an entertaining journey with Colonel Terry Virts as he takes you through the rules, lessons, procedures and experiences of space travel. A born storyteller, Virts reveals the often-untold side of what it takes to be an astronaut, from the thrill of the first blastoff, coping with 'space brain' and even how to deal with a dead crew member. Virts' refreshing take on astronaut life is described over 51 captivating chapters, jam-packed with compelling stories and inspiring life lessons.

FOR YOUR HOME

DELUXE GLOBE DECANTER SET

Cost: £59 (approx. $83.40)

From: MenKind

2 Fuel your adventurous spirit with this decanter shaped like a classic globe. The weight of the world – or in this case approximately 850 millilitres of whatever liquid you choose – rests on a sleek wooden cradle. The blown-glass decanter also contains a detailed ship inside and is accompanied by two matching glass tumblers, each embellished with continental markings. This deluxe decanter set certainly makes for quite the centrepiece, measuring approximately 26 by 24 by 24 centimetres (10.2 by 9.4 by 9.4 inches).

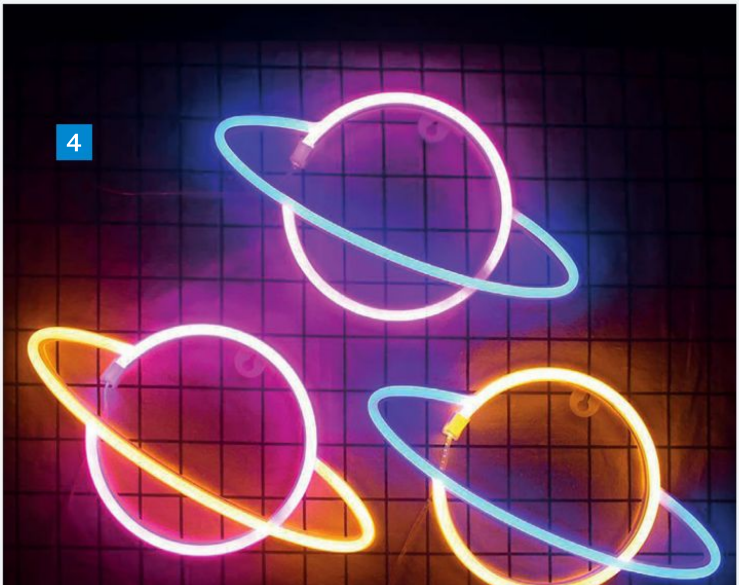
FOR STYLE

MARS EXPLORATION CREW JACKET

Cost: £120 (approx. $169.60)

From: Science Museum

3 Make an astronomical impact with this Mars Exploration Crew Jacket adorned with a variety of space-themed embroidered patches, including a NASA patch, Mars Exploration Crew patch and 'The Next Giant Leap' Mars patch. This unisex slim-fit jacket is a celebration of the next big step for humankind: manned exploration of the Red Planet. You don't need to wait for a Martian expedition to sport such a jacket, as it's more than fit for purpose here on Earth with its waterproof and windproof properties. Available in UK sizes S to XL.



4

6

“BASK IN THE COSMIC GLOW OF THIS LIGHT, WHICH IS AVAILABLE IN A VARIETY OF COLOURS”

5

FOR DECORATION

LED NEON LIGHT PLANET

Cost: £16.99 (approx. $24)

From: thelightzey.com

4 Add a touch of neon flare to your home with this quirky ringed planet light. Bask in the cosmic glow of this light, which is available in a variety of colours: warm white and pink, blue and pink or warm white and blue, all pink or all blue. The small and lightweight versatile design allows you to accessorise your space with ease, with it measuring 18 by 30 centimetres (7.1 by 11.8 inches). The planet is made from LED light tubes and powered by either AA batteries or via a USB power source.

FOR OBSERVERS

OKLOP PADDED BAG FOR SMALL TELESCOPES

Cost: £59 (approx. $82.86)

From: firstlightoptics.com

5 Carry your equipment with ease and full protection with this Oklop padded telescope bag, designed to fit refractors up to 120/1000 EQ2 and Newtonians up to 130/900 EQ2 with tube rings and dove tails fitted. The high-quality bag is manufactured in Europe and boasts a tough, water-resistant polyester outer fabric, a silky smooth inner liner and dense foam padding. In addition, the handles and straps are positioned at the centre of gravity, making them easier to carry, and the shoulder straps can be removed.

FOR FUN

GREAT LITTLE TRADING CO SPACE TEEPEE

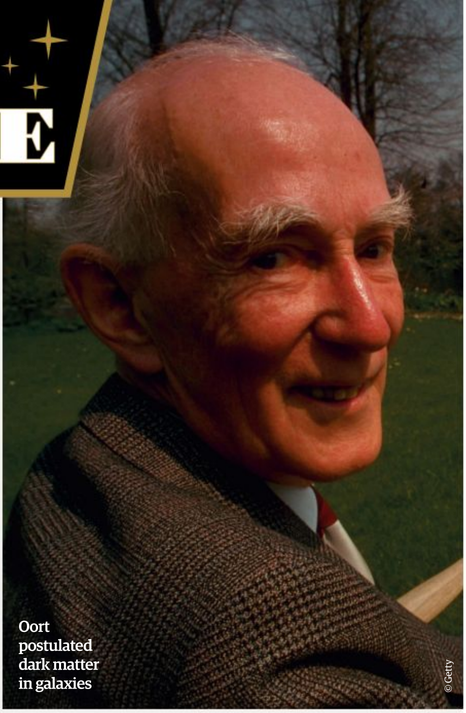
Cost: £78 (approx. $110.25)

From: John Lewis

6 Fuel your child’s creative play with this space-themed cotton canvas play tent decorated with stars, galaxies and planets. The practical design with a detachable washable base makes the tent suitable for both indoor and outdoor use and is suitable for children aged three years and up. The teepee stands approximately 155 centimetres (61 inches) tall, and self-assembly is required. Whether it’s a rocket ship destined for distant planets or shelter on an alien world, this play tent is the perfect space to let your child’s imagination take flight.

JAN HENDRIK OORT

One of the greatest astronomers of the 20th century, Oort revolutionised astronomy



Oort postulated dark matter in galaxies

© Getty

Jan Oort was a true trailblazer, approaching his astronomical research as both an astronomer and theorist with a broad range of interests. Throughout his established career Oort made remarkable contributions to the discipline and was responsible for numerous groundbreaking discoveries. As such the Oort Cloud, Oort constants and the asteroid 1691 Oort are all named after him.

In his 20s Oort had already determined that the Milky Way rotated like a giant pinwheel, with stars closer to the centre of the galaxy travelling much faster than those further out. Two constants derived by Oort – known as Oort constants A and B – underpinned this realisation and are still used in calculations of galactic rotation to this day. Through studying the motion of stars, Oort also revealed that our Sun was not at the centre of the Milky Way, but was in fact some 26,000 light years out in the galactic suburbs. Moreover, during his observations of star movement throughout our galactic home, Oort used the term 'dark matter' to describe the unidentified mass causing stars to move faster than calculations had predicted.

Ever perceptive, Oort was one of the first scientists to realise the true significance of using radio waves to investigate the cosmos. He theorised that clouds of hydrogen gas were loitering out in the spiral arms of the Milky Way, and it was in these gaseous plumes that stars were born. Oort predicted this before radio telescopes were able to confirm his theories. After World War II he was able to witness his ideas and theories become reality at the new Dutch radio observatories Dwingeloo and Westerbork.

One of his most notable contributions to astronomy is his theory that a vast reservoir of comets surrounds the Solar System. Though yet to be proven, his theory is widely accepted within the scientific community and has come to be known as the Oort Cloud. Oort had meticulously studied the orbits of long-period comets, noticing that many originated from a zone far beyond the orbit of Pluto. Encompassing the Solar System in a giant spherical shell, the Oort Cloud is thought to contain billions – if not trillions – of pieces of icy space debris and is home to most of the long-period comets we observe in our Solar System. Oort quite literally rewrote the textbooks on galactic motion and our understanding of the universe.

> "OORT ALSO REVEALED THAT OUR SUN WAS NOT AT THE CENTRE OF THE MILKY WAY"

Born in Franeker in the Netherlands, Oort attended the University of Groningen, where he enrolled at the age of 17 to study astronomy. After graduation he continued to work at the University of Groningen as an assistant for a year, then headed to the US to gain experience working at Yale Observatory for two years.

In 1924 Oort returned to the Netherlands, achieving his doctorate with a thesis titled 'The Stars of High Velocity' just two years later. Oort's research continued throughout World War II, and when the war ended he became the director of the Leiden Observatory, holding this position from 1945 to 1970. During this time Oort was also the general secretary of the International Astronomical Union, serving from 1935 to 1948. Throughout his career Oort won many coveted awards, one of the more prestigious being the Vetlesen Prize from Columbia University, which he won in 1966.

Oort passed away in 1992 at the age of 92. His revolutionary ideas and discoveries which shook the scientific world continue to shape our understanding of the universe to this day.

All About Space

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Staff Writer **Daisy Dobrijevic**
Production Editor **Nikole Robinson**
Research Editor **Baljeet Panesar**
Senior Art Editor **Duncan Crook**
Photography **Olly Curtis**

Contributors
William Alston, Stuart Atkinson, Ines Belgacem, Daniel Brown, Charles Q. Choi, Colin Stuart, David Crookes, Lewis Dartnell, Jacinta Delhaize, Ian Evenden, Robin Hague, Alexander J. van der Horst, Cameron Hummels, Robert Lea, Tereza Pultarova, Rahul Rao, Giles Sparrow, Mike Wall, Mindy Weisberger, Nigel Watson, Dimitri Veras

Cover images
Getty; NASA; Nicholas Forder;

Photography
Alamy; ESA; ESO; NASA; Science Photo Library; Shutterstock; SpaceX; University of Arizona; Wikipedia Commons;
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
UK Commercial Director **Clare Dove**
clare.dove@futurenet.com
Senior Advertising Manager **Amanda Burns**
amanda.burns@futurenet.com
0330 390 6036
Account Manager **Garry Brookes**
garry.brookes@futurenet.com
0330 390 6637

International Licensing and Syndication
All About Space is available for licensing and syndication. To find our more contact us at **licensing@futurenet.com** or view our available content at **www.futurecontenthub.com**.
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com

Subscriptions
Enquiries **help@magazinesdirect.com**
UK orderline & enquiries **0330 333 1113**
Overseas order line & enquiries **+44 (0)330 333 1113**
Online orders & enquiries **www.magazinesdirect.com**
CRM Director **Louise Dudfield**

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Senior Advertising Production Manager **Jo Crosby**
Digital Editions Controller **Jason Hudson**
Production Manager **Nick Williams**

Management
Chief Content Officer **Angela O' Farrell**
Commercial Finance Director **Dan Jotcham**
Managing Director **Sarah Rafati Howard**
Head of Art & Design **Greg Whitaker**

Printed by William Gibbons & Sons Limited, 26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9060

ISSN 2050-0548

All contents © 2021 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

If you submit material to us, you warrant that you own the material and/or have the necessary rights/permissions to supply the material and you automatically grant Future and its licensees a licence to publish your submission in whole or in part in any/all issues and/or editions of publications, in any format published worldwide and on associated websites, social media channels and associated products. Any material you submit is sent at your own risk and, although every care is taken, neither Future nor its employees, agents, subcontractors or licensees shall be liable for loss or damage. We assume all unsolicited material is for publication unless otherwise stated, and reserve the right to edit, amend, adapt all submissions.

Widely Recycled

We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this magazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards. The manufacturing paper mill and paper hold full FSC and PEFC certification and accreditation.

FUTURE
Connectors. Creators. Experience Makers.

Future PLC is a public company quoted on the London Stock Exchange (symbol: FUTR)
www.futureplc.com

Chief Executive **Zillah Byng-Thorne**
Non-executive Chairman **Richard Huntingford**
Chief Financial Officer **Rachel Addison**

Tel +44 (0)1225 442 244

ipso. Regulated

WAR THUNDER

New? GET YOUR FREE BONUS

Experience the Battle of Britain yourself in War Thunder!

PLAY NOW FOR FREE
WARTHUNDER.COM/FLY

Gaijin Entertainment
© 2009—2018 by Gaijin Entertainment. All rights reserved.

XBOX ONE PS4 Windows STEAM Mac oculus VIVE

12
www.pegi.info

Sky-Watcher®
Be amazed.

POPULAR BEGINNER & INTERMEDIATE NEWTONIAN REFLECTORS

Sky at Night MAGAZINE GROUP TEST WINNER

SKYHAWK-114 (EQ1)
114mm f/8.7 CATADIOPTRIC REFLECTOR
SRP £179

"The optics were so good.... the review instrument certainly delivered in every important respect"
BBC SKY AT NIGHT MAGAZINE

SKYHAWK-1145P (EQ1)
114mm f/4.4 PARABOLIC REFLECTOR
SRP £189

Sky at Night MAGAZINE GROUP TEST WINNER

EXPLORER-130P (EQ2)
130mm f/5 PARABOLIC REFLECTOR
SRP £279

"I was most impressed with the views revealed by the 'scope during tests...Highly recommended!"
ASTRONOMY NOW MAGAZINE

Astronomy HOT Product

EXPLORER-130 (EQ2)
130mm f/6.92 REFLECTOR
SRP £225

"This telescope made observing the night sky enjoyable....great views coupled with ease of use"
BBC SKY AT NIGHT MAGAZINE

Wi-Fi GO-TO

STAR DISCOVERY P150i
150mm f/5 Wi-Fi GO-TO PARABOLIC REFLECTOR
SRP £529

EXPLORER-150P (EQ3-2)
150mm f/5 PARABOLIC REFLECTOR
SRP £468

"Good for advanced observing... Saturn was a stunning sight"
BBC SKY AT NIGHT MAGAZINE

Sky at Night MAGAZINE HIGHLY COMMENDED 87%

EXPLORER-150PL (EQ3-2)
150mm f/8 PARABOLIC REFLECTOR
SRP £478

EXPLORER-200P (EQ5)
200mm f/5 PARABOLIC REFLECTOR
SRP £699

"Passed all our tests with flying colours and was a delight to use both optically and mechanically"
BBC SKY AT NIGHT MAGAZINE

Sky at Night MAGAZINE GROUP TEST WINNER

STARQUEST 130P
130mm f/5 PARABOLIC REFLECTOR
SRP £239

SKYLINER-150P CLASSIC
153mm f/7.8 PARABOLIC DOBSONIAN
SRP £319

"Turning to Saturn, the view really took our breath away....The Skyliner was a joy to use"
BBC SKY AT NIGHT MAGAZINE

SKYLINER-200P CLASSIC
203mm f/5.9 PARABOLIC DOBSONIAN
SRP £419

Sky at Night MAGAZINE HIGHLY COMMENDED 93%

SKYLINER-250P CLASSIC
254mm f/4.7 PARABOLIC DOBSONIAN
SRP £619

HERITAGE-76
76mm f/4 DOBSONIAN
SRP £79.99

Sky at Night MAGAZINE ★★★★★ REVIEWED IN Issue 111 August 2014

HERITAGE-100P
100mm f/4 PARABOLIC DOBSONIAN
SRP £135

HERITAGE-130P FLEXTUBE™
130mm f/5 PARABOLIC DOBSONIAN
SRP £205

HERITAGE-150P FLEXTUBE™
150mm f/5 PARABOLIC DOBSONIAN
SRP £255

THE ESSENTIAL Optical Product Guide
DISCOVER NEW IMAGING HORIZONS

Email for 88 Page FREE Catalogue

Available from dealers throughout the UK
OPTICAL VISION LIMITED

Full product details at:
www.opticalvision.co.uk
info@opticalvision.co.uk